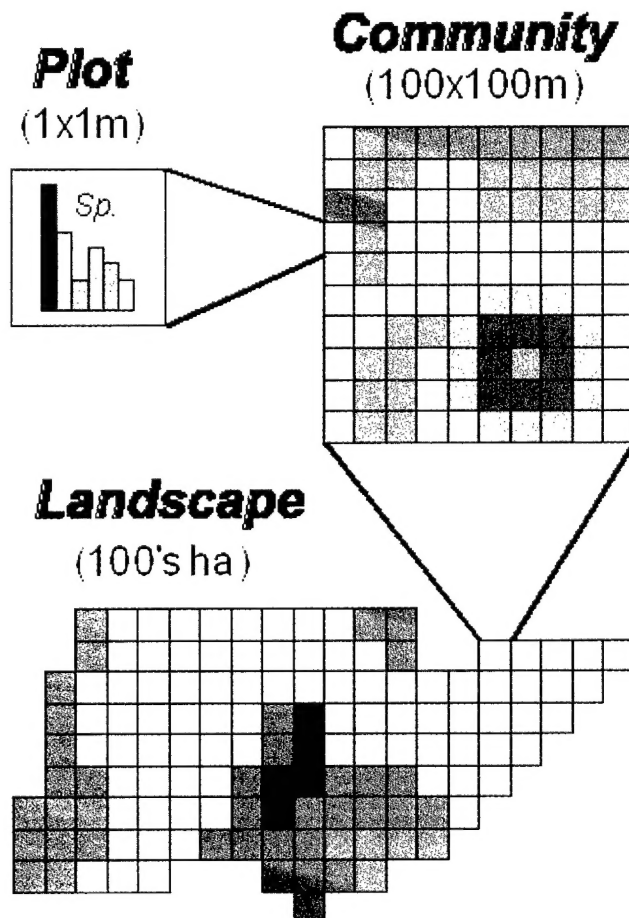Construction Engineering
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Engineer Research and
Development Center

EDYS Experimental and Validation Results for Grassland Communities

Terry McLendon, W. Michael Childress, Cade Coldren, and
David L. Price

August 2001

Plot
(1x1m)

Sp.

Community
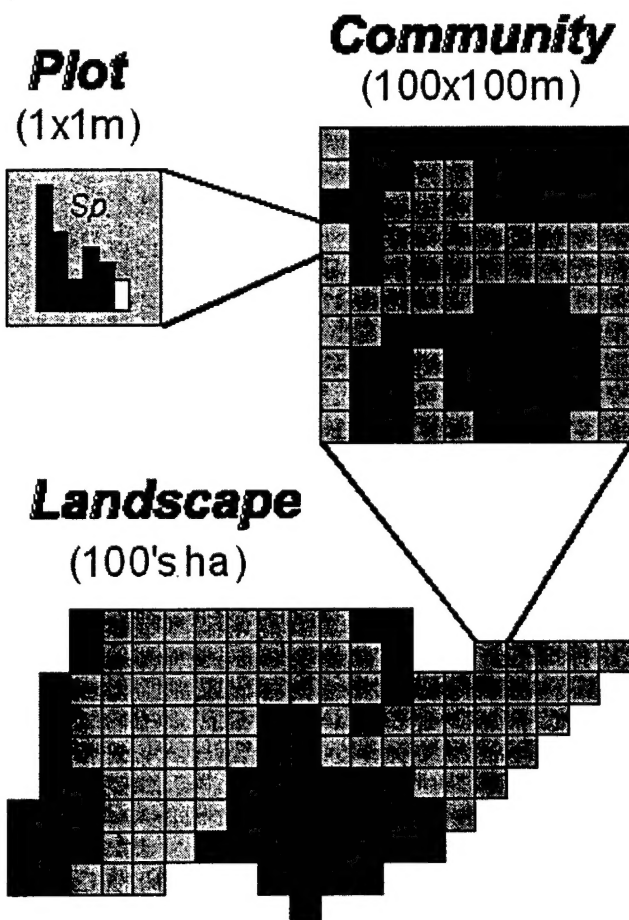(100x100m)

Landscape
(100's ha)

20011119 145

**US Army Corps
of Engineers.**
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Plot
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Community
(100x100m)

Landscape
(100's ha)

Foreword

the Land Based Carrying Capacity capability and provided essential data bases for the EDYS model regarding tracked and wheeled vehicle impacts and impacts of wildfires.

Drs. Terry Atwood and David Moffit, staff scientists of the National Water Management Center of the USDA Natural Resources Conservation Service, provided technical expertise, reviews of the EDYS model, and funding (Military Interdepartmental Purchase Order Request [MIPR] #677103712) to leverage the development and demonstration of the water dynamics module of the EDYS model.

The technical editor was Gloria J. Wienke, Information Technology Laboratory. Stephen E. Hodapp is Chief, CEERD-CN-N, and Dr. John T. Bandy is Chief, CEERD-CN. The associated Technical Director was Dr. William D. Severinghaus, CEERD-TD. The Acting Director of CERL is Dr. Alan W. Moore.

CERL is an element of the U.S. Army Engineer Research and Development Center (ERDC), U.S. Army Corps of Engineers. The Commander and Executive Director of ERDC is COL John W. Morris III, EN, and the Director is Dr. James R. Houston.

Executive Summary

The Ecological DYnamics Simulation (EDYS) model is a personal computer-based, mechanistic model that is a useful evaluation and planning tool for investigating potential plant, animal, and hydrological responses to anthropogenic and natural stressors in a wide variety of ecological systems. In this research, EDYS was used to simulate effects of military training, drought, fire, grazing, and soil nitrogen availability on grassland communities on Fort Bliss, Texas, and on Fort Hood, Texas.

Experimental field validation plots were established to test the accuracy of EDYS in predicting species and community dynamics in response to water and nitrogen availability. Baseline data were collected in early 1998 and the plots were resampled at the end of the growing seasons in 1998 and 1999. EDYS simulations were run using parameterizations based on these baseline data. The predicted 1998 and 1999 values from the simulations were compared to the sampled values to calculate accuracies of first- and second-year simulations.

This document reports the results of (1) the experimental water and nitrogen treatments, (2) the accuracies of the EDYS model in predicting these responses, and (3) examples of management applications of the EDYS model for both of the demonstration sites.

The Fort Bliss grassland communities on which the experiments were conducted were dominated by black grama. The response of this perennial grass to both water and nitrogen treatments was influenced by successional status of the plant community. On the later successional site, black grama increased in response to increased water and decreased in response to higher nitrogen. On the earlier successional site, black grama decreased as water increased and did not respond to the nitrogen treatment. We attribute this differential response to the ability of the more abundant earlier successional species at the earlier successional site to more rapidly use the additional water and nitrogen.

The Fort Hood study site was a midgrass prairie dominated by little bluestem. The water treatment did not result in a significant response in any of 15 vegetation variables. A longer study period is probably necessary to produce a statistically significant response. Nitrogen availability resulted in significant responses

in 4 of the 15 vegetation variables. Increased nitrogen availability increased the aboveground biomass of tall dropseed, prairie bluets, perennial forbs, and total aboveground biomass.

For the black grama communities at Fort Bliss, the second-year validation EDYS simulations were 94% accurate for total aboveground biomass, 99% accurate for total grasses, 93% accurate for black grama, and 83% accurate for the weighted average for all species. EDYS simulations were less accurate for shrubs (48%), forbs (33%), and 3 of the 4 secondary perennial grasses. The values predicted by EDYS were not statistically different from sampled values for total aboveground biomass, total grasses, snakeweed, black grama, and sand dropseed, indicating that the EDYS simulations were at least as accurate as the field sampling techniques for those variables. EDYS accurately simulated the experimental responses to the water and nitrogen treatments and the differences between sites.

Results of 40-year simulations of anthropogenic and natural stressors on the Fort Bliss black grama community were similar to those reported from field research studies. Fire is an effective method of controlling shrubs in this plant community, but if fire events are too frequent they will be detrimental to black grama. The EDYS simulations indicate that a 15-year fire frequency should reduce shrub densities and be safe to black grama. Cattle grazing at a stocking rate of 60 acres per animal unit (Ac/AU) can be safely sustained for about 10 years, after which black grama productivity and abundance begins to decrease and shrub abundance increases. This grassland community can withstand a 10% decrease in precipitation for about 20 years without major changes in species composition, if ungrazed by cattle. After 20 years of below normal precipitation, even without livestock grazing, compositional changes will occur. Black grama will decrease and shrubs will increase. With cattle grazing, the effect of drought is intensified. With a 10% decrease in precipitation and a stocking rate of 45 Ac/AU, the 10-year effect was twice as great as decreased precipitation alone.

For the little bluestem grassland at Fort Hood, the second-year validation simulations were 99% accurate for total aboveground biomass, 89% accurate for total grasses, 82% accurate for little bluestem, 90% accurate for Texas wintergrass, 85% accurate for broomweed, 96% accurate for sedge, and 70% accurate for the weighted average for all species. EDYS simulations were less accurate for forbs (64%) and 4 of the 8 individual species. The values predicted by EDYS were not statistically different from sampled values for total aboveground biomass, total grass biomass, and 4 of the individual species. Overall, the EDYS simulations were 84% and 80% accurate in predicting plant responses to the water and nitrogen treatments, respectively.

Forty-year simulations for the little bluestem community indicate that a cattle stocking rate of 40 Ac/AU year long will not have detrimental effects on this community and a stocking rate of 20 Ac/AU will reduce some species but not the overall productivity of the community. A long-term 10% decrease in precipitation would result in significant changes in the plant community. The relative amounts of shorter grasses would increase and the midgrasses would decrease. Without fire, juniper will dominate the site in 20 years and will largely exclude most grasses within 60 to 70 years. Ten-year fire frequencies were effective in reducing the amount of juniper and allowed the community to remain dominated by little bluestem. Twenty-year fire frequencies were much less effective in controlling juniper. Over a 40-year simulation period, juniper invasion of the little bluestem grassland reduced water export (surface runoff + subsurface recharge) by 23%, compared to the juniper-free grassland.

The results of this 2-year validation study indicate that EDYS is an effective and accurate tool for predicting vegetation responses to both natural ecological stressors and changes in management scenarios in study sites containing similar parameters (two very different grassland ecosystems: a desert grassland and a midgrass prairie). EDYS second-year accuracies were 94-99% for total above-ground biomass, 89-99% for total grasses, 82-96% for major species, and 70-83% for all species on a weighted biomass basis. EDYS effectively simulated plant community responses to fire, livestock grazing, successional status, precipitation variations, and changes in soil nitrogen availability.

Contents

List of Figures and Tables

1 Introduction

Background

Precipitation patterns, including the effects of long-term droughts or above average precipitation and the interactions with nitrogen availability, often have enough influence on plant growth that the effects of our use or management of land are not apparent. This is especially true because of the need to try to judge changes in land condition over periods of months to years.

One of the primary information requirements identified by Army land managers and trainers is the need to be able to project the impacts of training and management strategies on the amount of plant cover protecting the soil. Managers also need to know how long it takes the plant community to recover to the desired plant cover level after over use.

Objective

The purpose of this research project was to test the ability of the Ecological Dynamics Simulation (EDYS) model to accurately project plant dynamics given the wide range of precipitation patterns and nitrogen availability over a period of years to decades.

This report presents three sets of results from this study: (1) experimental results of the water and nitrogen availability study, (2) validation results of the EDYS model, and (3) EDYS simulations of the dynamics of these two grasslands in response to drought, livestock grazing, fire, and invasion of woody plants.

Approach

Experimental plots were established in two dissimilar grassland ecosystems: a black grama grassland at Fort Bliss, TX, and a little bluestem prairie at Fort Hood, TX. Two experimental treatments (addition of water and control of soil nitrogen availability) were implemented at each site to test the ability of EDYS to accurately predict the effects of these two important ecological stressors. Once

validated, EDYS was used to predict the response of these two grasslands to various management scenarios. Of particular interest at both installations are the impacts of livestock grazing, invasion of woody species, and prescribed fire.

Mode of Technology Transfer

This report will be made accessible through the World Wide Web (WWW) at URL:

http://www.cecer.army.mil

2 A Description of EDYS

The Ecological DYnamics Simulation (EDYS) model is a personal computer-based, mechanistic, spatially explicit simulation model developed by Terry McLendon and Michael Childress (Childress et al. 1999a, 1999b). EDYS simulates changes in soil, water, plant, animal, and landscape components resulting from natural and anthropogenic ecological stressors. It can be applied to a wide variety of ecosystems and numerous management or disturbance scenarios.

EDYS consists of modules for Climate, Soil, Hydrologic, Plant, Animal, Stressor, Spatial, Landscape, and Management. Climatic inputs can be generated historical or stochastically, or a combination of the two. The Soil Module is divided into layers (horizons, subhorizons, or artificial layers), the number, depth, and physical and chemical characteristics of which are site-specific for each application. The Hydrologic Module provides for infiltration and water movement through the soil profile, surface movement of water, surface erosion, sediment movement, subsurface movement of water, and changes in water quality. The Plant Module includes aboveground and belowground components for each species included in each user-defined suite of user needs. Plant growth is dynamic in relation to plant components (e.g., roots, trunk, stems, leaves, seeds, and standing dead), season, resource requirements (water, nutrients, sunlight), and stressors (e.g., herbivory, competition, fire, trampling, chemical contaminants). The Animal Module consists of basic population parameters and diet attributes (preferences, utilization potential, competitive success) for each species (e.g., insects, rodent, native ungulates, livestock). The Stressor Module includes drought, nutrient availability, fire, herbivory, trampling (foot and vehicle), contaminants, shading, and competition (soil moisture, nutrients, food). The Spatial Module allows growth of individual plants (e.g., trees) and distribution patterns (e.g., colonies, fire patterns, soil heterogeneity) to be explicitly represented in the simulations. The Landscape Module allows for multi-scale simulations: fine scale (1 m^2 or smaller), patches (e.g., 100 m^2), communities (e.g., 1 to 10 hectares), and landscapes and watersheds (1 km^2 and larger). Time intervals vary from day (e.g., precipitation events, plant water demand, fire, herbivory), to month (e.g., species composition), to a year and longer (e.g., climatic cycles).

EDYS has been, or is currently being, applied to over 40 ecological communities. Current applications are at seven National Parks, five U.S. Army installations

(McLendon et al. 1998, 1999a), the U.S. Air Force Academy (McLendon et al. 1999b, 1999c), one U.S. Marine Corps installation, an Australian Army installation (Ash and Walker 1999), two Natural Resource Conservation Service watersheds, one ecological research site, one wildlife management area, and four mine sites. The simulated communities include deserts, forests, grasslands, shrublands, wetlands, woodlands, and highly disturbed areas. Current application locations are in California, Colorado, Maine, Montana, Nevada, New Mexico, Texas, Utah, Washington, Wyoming, Australia, and Indonesia.

EDYS is designed to simultaneously simulate ecosystem dynamics at three different spatial scales: Plots, Communities, and Landscapes (Figure 1). This approach allows adequate representation of ecological processes that operate at different spatial and temporal scales. Because EDYS uses mechanistic representations of each process at the most appropriate scale, linkages among different components of the community, ecosystem, and landscape can be projected with reasonable confidence.
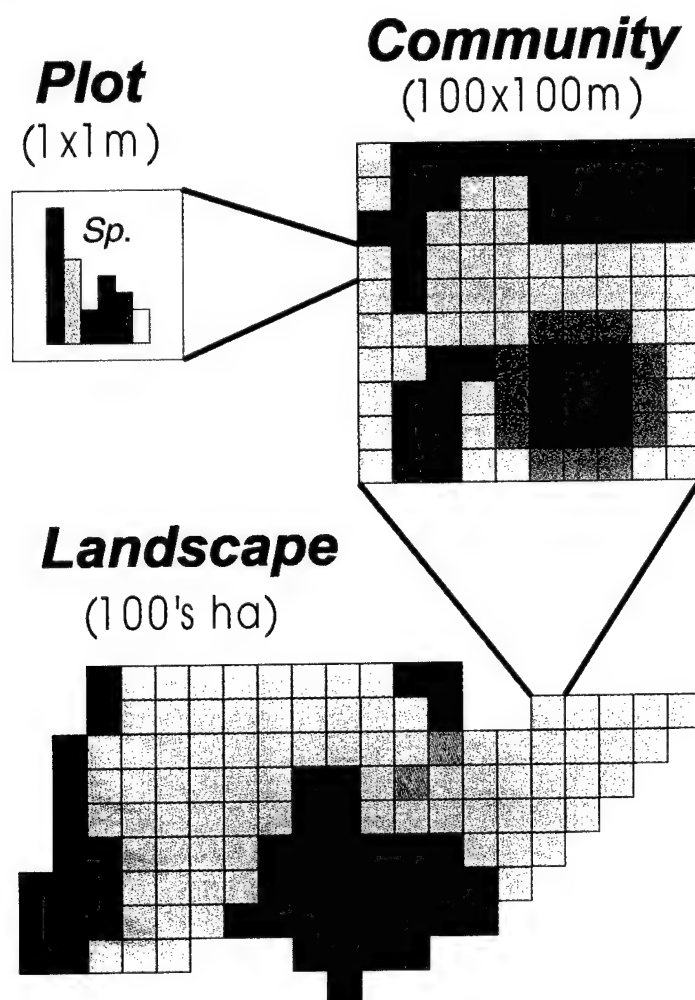
Figure 1. Scaling of the Plot, Community, and Landscape modules in EDYS.

The Plot Module in EDYS simulates ecological mechanisms and dynamics at the small scale (1 m^2 to 400 m^2). Most of the processes in EDYS related to plants (e.g., growth, water and nutrient uptake, and competition) and soils (e.g., water and nutrient transport through the profile, decomposition) are implemented in this module (Figure 2). This module is comprised of a number of submodules, including Climate, Soil, Hydrologic, Plant, and Animal. Climatic inputs, primarily precipitation and evapotranspiration potential, are based on historical data, stochastically generated, or some combination of both.
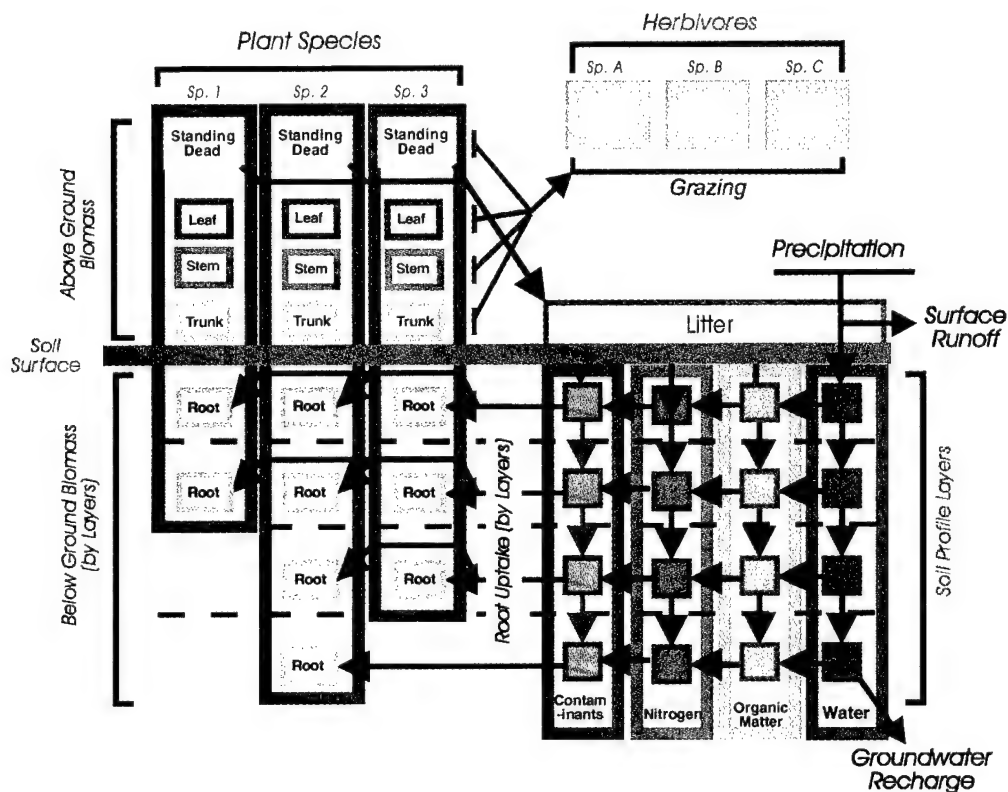
Figure 2. EDYS Plot-level structure.

The Soil Module represents the soil profile by partitioning it into up to 13 different layers (horizons, subhorizons, or artificial layers). This representation incorporates the vertical depth, water content and holding capacity, nitrogen content, organic matter content, microbial activity, decomposition, and contaminant content and activity for each layer. The Hydrologic Module simulates small-scale precipitation dynamics, including interception by aboveground plant biomass; surface runoff; erosion and sediment mobilization; infiltration of water through the profile; mobilization and transport of nitrogen, organic matter, and contaminants; and subsurface export of water out of the profile.

The Plant Module represents the dynamics of aboveground and belowground components for each major plant species. Plant growth is simulated for each

component (roots, trunk, stems, leaves, seeds, and standing dead), relative to season, resource requirements (water, nutrients, sunlight), and stressors (e.g., herbivory, competition, fire, trampling, chemical contaminants). The Animal Module consists of basic population parameters and diet attributes (preferences, utilization potential, competitive success) for each specified species (e.g., insects, rodent, native ungulates, livestock).

Different plots are represented as cells in the Community Grid (Figure 1). The Community Module focuses on spatial patterns and the dynamics of scales from the patch (400 m^2) to the community (1 to 10 hectares). These include spatial heterogeneity in soils, plants, and stressors among plots within the community, stressors such as fire propagation, grazing, and lateral flow of surface and sub-surface water and materials, and important spatial patterns such as vegetation cover, habitats, and topography.

In an analogous manner, communities are the basic units in the Landscape Grid (Figure 1). This largest scale module focuses on ecological processes operating at large spatial scales (1 km^2 and larger). These processes include fire initiation regimes, climatic regimes, watershed-level water movement and transport of materials, and management practices such as training scheduling, grazing operations, and weed control.

EDYS Simulation Outputs

Each simulation run of EDYS produces a large volume of data for all state variables (e.g., plant biomasses, soil water and soil nutrient contents, total surface runoff) and processes (e.g., water and nutrient transport and balances, plant production). These data are stored in a series of large text tables, typically on a monthly basis (e.g., Table 1). Many of these data are also presented in graphical displays at the end of the simulation run (e.g., Figure 3).

These extensive output files serve a number of functions. For example, these data are required for accurately testing and calibrating the EDYS application for particular communities and sites. In addition, these data can be sent in "real time" to other models running simultaneously. Special files for rapid data exchange are now being developed to link EDYS with CASC2D, an advanced watershed-level rainfall-runoff model implemented at the U.S. Army ERDC/ Coastal and Hydraulics Laboratory, and with the Army Training and Testing Area Carrying Capacity (ATTACC), methodology that estimates vegetation dis-

turbance effects of various military training activities at U.S. Army Installations.

Table 1. Simulated water, nitrogen, and organic pools in each soil layer of three different plot types in the little bluestem community at Fort Hood; produced by EDYS simulation run.

Quad 101				A	A	Bt1	Bt1	Bt1	Bt2	Bt2	Bk1	Bk1	Bk2	C	C	C
Yr	Mon	Class*	Tot	1	2	3	4	5	6	7	8	9	10	11	12	13
0	0	Depth	3048.0	25.4	76.2	152.4	152.4	177.8	228.6	228.6	228.6	203.2	254.0	304.8	304.8	711.2
0	0	Water	79.2	2.8	9.1	19.8	21.3	26.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		Avl N	2.2	0.1	0.2	0.3	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.2
		OM	13360	3476	9144	16284	10236	10754	12682	11504	10288	7924	7874	6828	3902	22758
		OMN	4 4312.0	134.6	354.3	597.7	487.3	442.9	460.6	372.2	301.8	215.0	220.5	219.5	175.6	330.0

Quad 201				A	A	A	A	A	AK	AK	AK	AK	CrK	CrK	CrK	CrK
Yr	Mon	Class	Tot	1	2	3	4	5	6	7	8	9	10	11	12	13
0	0	Depth	558.8	25.4	25.4	25.4	50.8	76.2	50.8	50.8	50.8	25.4	25.4	50.8	50.8	50.8
0	0	Water	40.9	1.5	3.3	5.3	9.9	17.5	5.1	4.6	4.1	1.8	1.5	2.5	2.5	1.3
		Avl N	0.4	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		OM	12642	1041	1016	1038	2121	2492	1622	1570	1041	189	134	189	142	47
		OMN	707.5	44.4	43.5	42.3	91.1	128.0	78.8	69.9	67.7	32.3	30.7	50.4	24.4	3.9

Quad 301				A1	A1	A1	A2Bkm	A2Bkm	A2Bkm	A2Bkm	A2Bkm	Ck	Ck	Ck	Ck	Ck
Yr	Mon	Class	Tot	1	2	3	4	5	6	7	8	9	10	11	12	13
0	0	Depth	1498.6	25.4	76.2	101.6	76.2	76.2	76.2	127.0	152.4	152.4	152.4	152.4	152.4	177.8
0	0	Water	79.2	2.5	9.1	15.2	9.9	7.6	7.6	11.4	13.7	2.1	0.0	0.0	0.0	0.0
		Avl N	0.9	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.0
		OM	28501	1083	3292	4406	3138	2492	2432	4002	4292	1170	829	585	439	341
		OMN	1777.9	45.6	133.7	179.4	134.8	128.0	118.1	178.3	209.7	1999.9	190.2	156.1	75.6	28.4

Quad 101				A	A	Bt1	Bt1	Bt1	Bt2	Bt2	Bk1	Bk1	Bk2	C	C	C
Yr	Mon	Class	Tot	1	2	3	4	5	6	7	8	9	10	11	12	13
1	Jan	Depth	3048.0	25.4	76.2	152.4	152.4	177.8	228.6	228.6	228.6	203.2	254.0	304.8	304.8	711.2
		Water	128.0	0.0	9.1	19.8	21.3	26.7	32.0	19.0	0.0	0.0	0.0	0.0	0.0	0.0
		Avl N	3.5	0.0	0.2	0.5	0.5	0.5	0.6	0.4	0.2	0.1	0.1	0.1	0.1	0.2
		OM	13358	3335	9041	16235	10331	10760	12748	11561	10288	7924	7874	6828	3902	22758
		OMN	6 4309.3	129.1	350.3	596.4	488.9	444.2	463.7	374.3	301.8	215.0	220.5	219.5	175.6	330.0

Quad 201				A	A	A	A	A	AK	AK	AK	AK	CrK	CrK	CrK	CrK
Yr	Mon	Class	Tot	1	2	3	4	5	6	7	8	9	10	11	12	13
1	Jan	Depth	558.8	25.4	25.4	25.4	50.8	76.2	50.8	50.8	50.8	25.4	25.4	50.8	50.8	50.8
		Water	40.6	0.0	1.8	2.0	4.6	7.6	5.1	4.6	4.1	1.8	1.5	2.5	2.5	2.5
		Avl N	0.6	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.1	0.0	0.0
		OM	12630	983	1017	1038	2090	2493	1638	1568	1059	221	138	187	144	54
		OMN	706.8	42.0	43.5	42.4	89.6	127.4	79.7	70.1	67.6	33.3	30.7	49.6	25.6	5.2

Quad 301				A1	A1	A1	A2Bkm	A2Bkm	A2Bkm	A2Bkm	A2Bkm	Ck	Ck	Ck	Ck	Ck
Yr	Mon	Class	Tot	1	2	3	4	5	6	7	8	9	10	11	12	13
1	Jan	Depth	1498.6	25.4	76.2	101.6	76.2	76.2	76.2	127.0	152.4	152.4	152.4	152.4	152.4	177.8
		Water	123.2	0.0	9.1	15.2	9.9	7.6	7.6	11.4	13.7	12.2	10.7	9.1	7.6	8.9
		Avl N	1.7	0.0	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.1	0.1	0.1
		OM	28473	1036	3249	4401	3142	2497	2431	3975	4290	1233	838	591	442	346
		OMN	1776.1	43.6	132.0	179.1	134.8	127.6	118.3	177.4	209.2	199.9	190.6	157.1	77.0	29.4

Note: Water in kg/m^2; Available N, OM, OMN in g/m^2. EDYS 2-21 May 1998, Fort Hood, TX, little bluestem ecotone, monthly soil pools — Soil.txt.
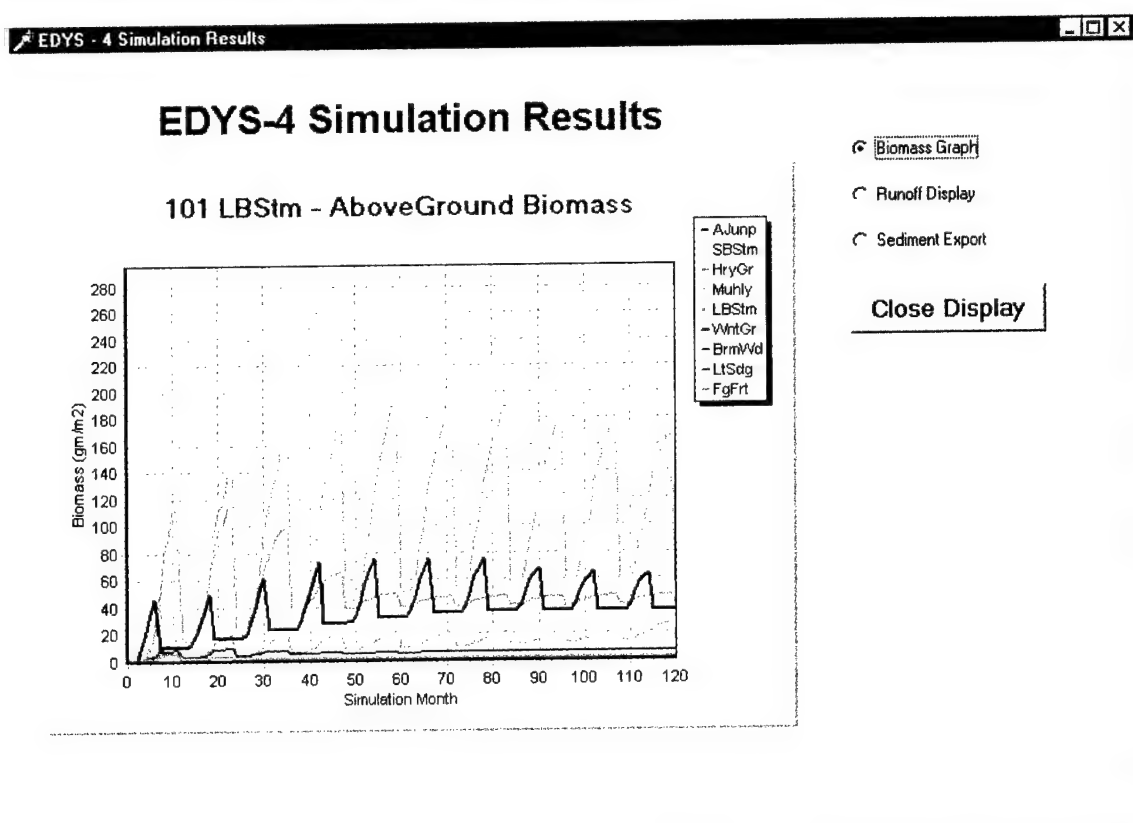
Figure 3. Monthly aboveground biomass of plant species in a 10-year simulation run of the little bluestem community at Fort Hood.

Hydrological Dynamics in EDYS

An important component of EDYS at all scales is hydrological dynamics. The Plot Module focuses primarily on one-dimensional movement of water up and down in the soil profile. Precipitation events deliver water to each plot, which then percolates down into different layers in the profile. Evaporation removes water from the top horizons, and a portion of the uptake by plant roots in each horizon is transpired as plants grow. The Community and Landscape Grids allow explicit representation of transport of water among different plots and soil horizons (Figure 4). This representation allows calculation of surface runoff, subsurface export, and transport of sediment, nutrients, and contaminants across the landscape.
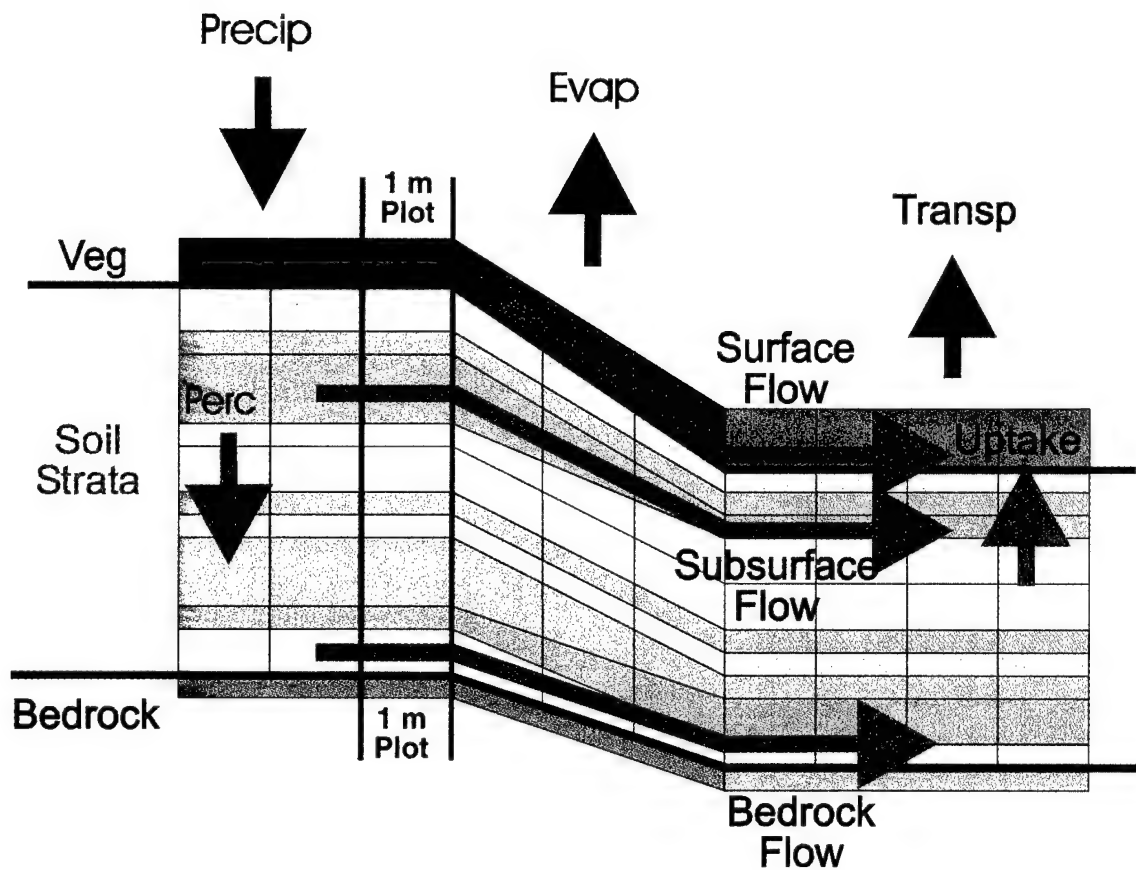
Figure 4. Hydrological dynamics in the EDYS Landscape module.

Among the various outputs produced in each EDYS simulation run are tables describing water pools and dynamics as well as summary graphical displays of total landscape runoff and export (Figure 5). These outputs allow projection of the effects of different climatic regimes, ecological stressors, vegetation dynamics, and management practices on surface and subsurface water quantity and quality.

Effects of Invasion of Juniper

These simulation outputs demonstrate (Figure 5) the potential effect of juniper invasion on vegetation dynamics in the grassland community. Juniper rapidly increases in biomass until it dominates the quadrat, while little bluestem is reduced to half of the biomass observed without juniper.
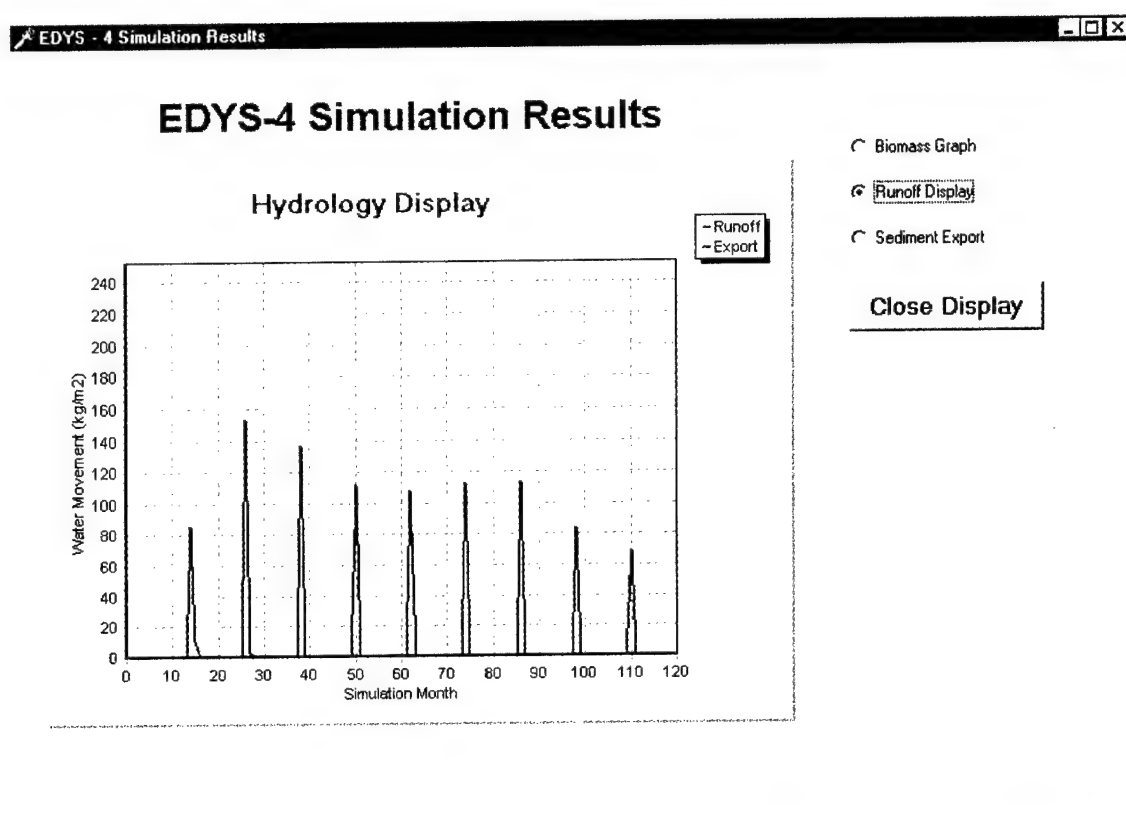
Figure 5. Projected surface runoff and subsurface export from the little bluestem community at Fort Hood.

The invasion of juniper into native grasslands has important implications for water quantity and quality, although the effects are highly site-specific. The dense canopies and dense roots and leaf litter effectively exclude all other plant species, and 100% canopy closure can occur in 40 years in some areas of the Edwards Plateau in Texas.

Juniper canopies substantially increase interception of precipitation over that of grasses, resulting in a significant decrease in the amount of water than reaches the soil surface (Figure 6). Evaporation of water from the surface is highly site-specific, depending on amount of bare ground, height and density of vegetation, and water-holding capacity of the top soil layers.
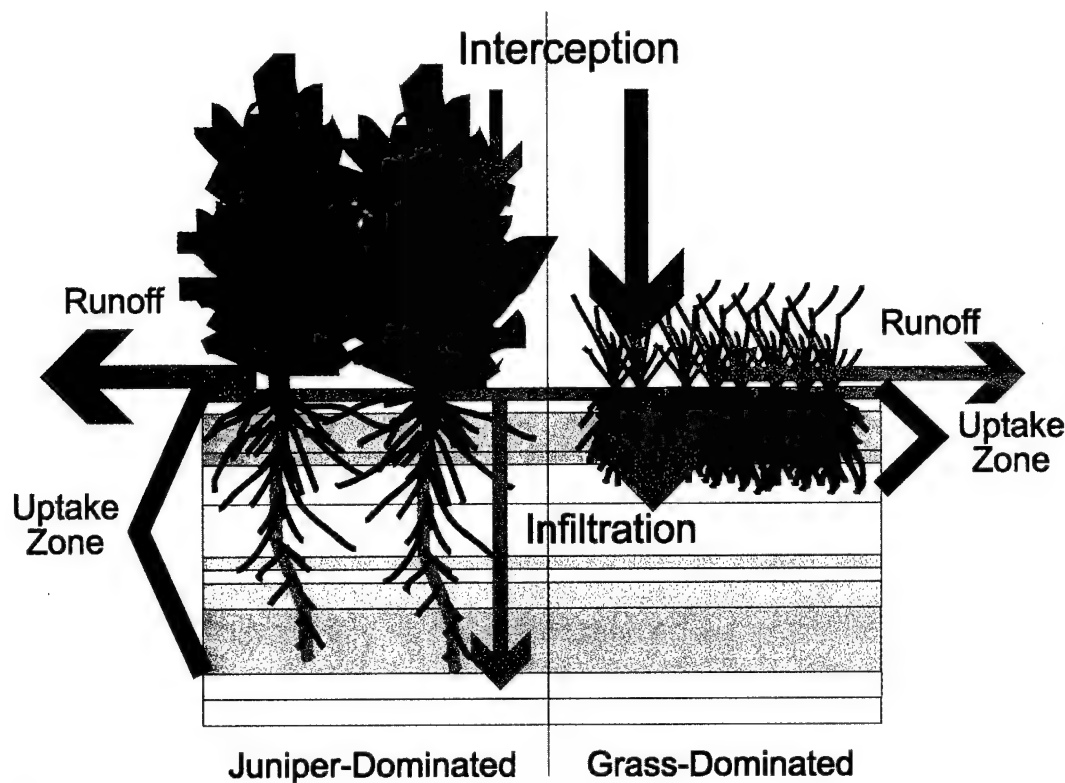
Figure 6. Hydrological dynamics in grassland and juniper woodlands.

Because the ground is essentially bare under the juniper, there is little material to stop or slow surface runoff of water to facilitate infiltration into the soil profile. This high energy flow picks up substantial quantities of sediment, resulting in considerable erosion. In dense grasslands, however, the dense plant material and litter substantially slow any sheet flow, allowing the water time to move into the soil profile. The water that does move across the surface is low energy flow with little erosive power, and suspended materials are effectively filtered out.

The root zones under grasses are filled with fibrous roots, which can take up considerably more water for transpiration than the less dense root zones under the junipers. However, any water that does pass below the grass root zone escapes transpiration, and moves laterally as subsurface flow or down into the groundwater recharge zones. Although more water initially enters deeper soil horizons under the juniper, this water is still accessible to uptake by the considerably deeper roots of the juniper. The actual difference in subsurface recharge under each community type is therefore greatly dependent on the profile depth and age and the root depth of the juniper stand.

Management Options

EDYS contains a large number of management options. An important management option at Fort Hood is prescribed fire. In this simulation (Figure 7), a controlled burn is conducted in the community every 8 years in August. Figure 7 indicates the effect on aboveground biomass of these burns in the little bluestem quadrat type. The juniper biomass is almost entirely eliminated by the burn in year 8. The little bluestem biomass responds to the reduction of juniper by increasing to levels approaching those in the simulation without juniper invasion. Little bluestem is well-adapted to fires, so it is only temporarily affected by these control burns even during the growing season.
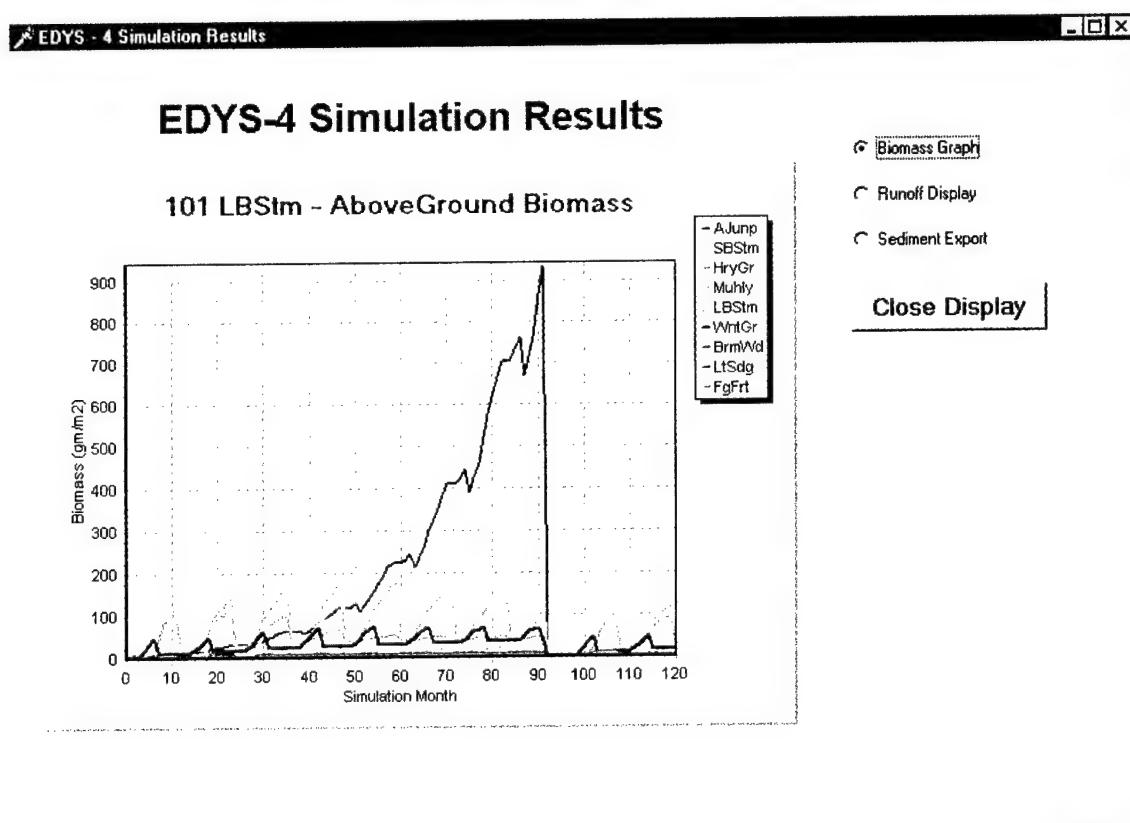
Figure 7. Monthly vegetation dynamics in the little bluestem quadrat type in an EDYS simulation implementing invasion of juniper and controlled burns.

3 Experimental Design and Methodology

The desert grassland study sites at Fort Bliss, in western Texas and southern New Mexico, are located on Otero Mesa, approximately 60 km northeast of the El Paso International Airport. Two sites were selected in 1997 for the establishment of the manipulative experiment. The sites are approximately 0.5 km apart and both are dominated by black grama (*Bouteloua eriopoda*). One site was last burned in June 1995; the second site has not been burned since 1986. Although both sites are dominated by black grama (72% and 81%, respectively), there are significant differences in species composition between them, and these differences may not be entirely attributable to time since last burned. The more recently burned site has twice as much shrubs and three times as much succulents as the 1986 burned site; the 1986 burned site has correspondingly more perennial grasses. Because of these differences, the two sites have been treated as two different communities in the study, rather than replicates of the same community. Both sites are grazed by cattle.

The midgrass prairie study site is located at Fort Hood, in central Texas. Experimental plots were established in Training Area 26A, South Fort Hood, approximately 5 km SE of Gray Army Air Field and 8 km SW of Killeen. The site is located on a south-facing slope of a low hill, in an open grassland between groves of juniper and oak. The study plots are dominated by little bluestem (*Schizachyrium scoparium*). The area is lightly trained on and is infrequently burned in accidental fires. Livestock grazing was reinstituted in mid-1998 after being excluded for 5 years.

Four blocks were established at each of the three study sites (two black grama sites at Fort Bliss and one little bluestem site at Fort Hood) in 1997 to serve as replications. Six plots, 10 m x 10 m each, were established in each block. Two experimental treatments, moisture and nitrogen, were initiated in late-1998. There are two moisture levels: high water and moderate water (control). There are three nitrogen levels: high available nitrogen (N-fertilizer added), moderate available nitrogen (no additions, control), and low available nitrogen (sucrose added, McLendon and Redente 1992). Two levels of the moisture treatment and three levels of the nitrogen treatment result in six treatment combinations in a completely randomized design. Each of the six plots per block was randomly assigned one of the six moisture-nitrogen treatment combinations.

The high water treatment at the Fort Bliss sites consisted of the addition of 3.32 cm of water, applied in two equal applications (8 to 10 Oct 1998 and 10 to 12 May 1999). The 3.32 cm represents an 8% increase in the precipitation received on Otero Mesa in the year preceding watering (Nov 97 to Oct 98). The high water treatment at the Fort Hood site consisted of the addition of 3.81 cm of water, applied from 27 to 29 Apr 1999. This amount represents a 4% increase in the average annual precipitation received in the preceding year (100.97 cm or 39.75 inches) and 5% of the long-term average annual precipitation (80.14 cm or 31.55 inches), based on data from Gray Army Air Field. All water applications were made from water trucks, using hoses with spray nozzles. Gravity-fed application rates were approximately 1.13 L/sec (0.3 gal/sec).

The high-N treatment consisted of the application of ammonium nitrate fertilizer at a rate of 10 g N/m^2 (100 kg N/ha) per year, applied in equal applications. A total of four applications were made at Fort Bliss: 5 Sep 1998, 26 Feb, 21 Sep, and 31 Oct through 6 Nov 1999. Three applications were made at Fort Hood: 20 and 21 Oct 1998; and 19 Mar, and 18 through 22 Oct 1999. The low-N treatment consisted of the application of sucrose at a rate of 27 g C/m^2 (267 kg C/ha), per application. Five applications were made at Fort Bliss: 5 Sep 1998; 26 Feb, 10 through 12 May, 21 Sep, and 31 Oct through 6 Nov 1999. Four applications were made at Fort Hood: 20 and 21 Oct 1998, 19 Mar, 26 through 29 Apr, and 18 through 22 Oct 1999.

Aboveground biomass was sampled by randomly locating 10 0.5-m^2 quadrats in each plot and clipping the herbaceous plants, by species, to ground level and clipping current-year's growth from shrubs. The clipped material was dried to 50 °C and weighed by species. Baseline samples were collected on 14 through 20 Feb 1998 at Fort Bliss and 17 through 20 Mar 1998 at Fort Hood. First-year validation samples were collected on 8 through 10 Oct 1998 at Fort Bliss and 19 and 20 Oct and 18 through 20 Nov 1998 at Fort Hood. Second-year validation samples were collected on 30 Oct through 6 Nov 1999 at Fort Bliss and 18 through 22 Oct 1999 at Fort Hood.

Belowground (root) biomass was sampled by taking one 20-cm root core from the center of each clipped quadrat. The samples were washed and the root material dried to 50 °C, weighed, and ashed. Belowground biomass samples were collected at Fort Bliss on 26 Feb 1999 and at Fort Hood on 19 Oct and 19 and 20 Nov 1998 and 18 through 22 Oct 1999.

4 Experimental Results and Discussion

Black Grama Grassland, Fort Bliss

Black grama dominated both of the Fort Bliss study sites, contributing 81% of the total aboveground biomass on the 1986-burned site and 72% of total aboveground biomass on the 1995-burned site (Table 2). Sand muhly (*Muhlenbergia arenicola*) was the second most abundant species (6%) on the 1986-burned site, followed by sand dropseed (*Sporobolus cryptandrus*, 3%), snakeweed (*Gutierrezia sarothrae*, 2%), and yucca (*Yucca elata*, 2%). Perennial grasses contributed 92% of the aboveground biomass, shrubs 4%, and perennial forbs 3%.

Composition of secondary species was different on the 1995-burned site, compared to the 1986-burned site. Creosotebush (*Larrea tridentata*) was the second most abundant species (7%), followed by sand muhly (4%), blue grama (*Bouteloua gracilis*, 4%), cholla (*Opuntia imbricata*, 3%), burrograss (*Scleropogon brevifolius*, 2%), sand dropseed (2%), and bush muhly (*Muhlenbergia porteri*, 1%). Perennial grasses contributed 87% of aboveground biomass on the 1995-burned site, shrubs 8%, succulents 3%, and perennial forbs 2%. Species diversity was approximately equal between the two sites.

Total standing crop biomass and biomass of perennial grasses were equal between the two sites, when averaged over the three sampling dates (Table 3). However, perennial grass biomass was lower on the 1995-burned site than on the 1986-burned site at the end of both growing seasons (Oct 1998 and Oct 1999). Shrub biomass remained relatively constant on the 1995-burned site but varied significantly over the three sampling dates on the 1986-burned site. The reverse was the situation for succulents. Succulent biomass remained relatively constant over dates on the 1986-burned site but varied significantly on the 1995-burned site.

Table 2. Species composition (% relative biomass) of the black grama grassland community at the Fort Bliss Otero Mesa study site.

Species/Lifeform	Last Burned 1986				Last Burned 1995			
	Feb 98	Oct 98	Oct 99	Mean	Feb 98	Oct 98	Oct 99	Mean
Ceratoides lanata	0.1	0.3	0.6	0.3	0.0	0.0	0.0	0.0
Condalia ericoides	0.0	0.0	0.4	0.1	0.0	0.0	0.0	0.0
Flourensia cernua	0.0	0.0	0.0	0.0	0.0	1.3	0.0	0.4
Gutierrezia sarothrae	0.1	2.9	2.7	1.9	0.1	0.3	0.2	0.2
Koberlina spinosa	0.0	0.0	0.0	0.0	0.0	0.8	0.2	0.3
Larrea tridentata	0.0	0.0	0.0	0.0	6.7	4.6	10.5	7.3
Prosopis glandulosa	0.0	0.0	0.1	t	0.0	0.0	0.0	0.0
Yucca elata	0.0	5.3	0.1	1.8	0.0	0.0	0.1	t
Opuntia imbricata	0.0	0.5	0.0	0.2	0.0	7.4	1.6	3.0
Opuntia macrocentra	0.0	0.0	0.0	0.0	t	0.4	0.0	0.1
Opuntia polyacantha	2.2	0.1	0.5	0.9	0.0	0.2	0.1	0.1
Aristida barbata	0.0	0.1	0.1	0.1	0.0	0.0	0.2	0.1
Aristida purpurea	0.2	t	0.1	0.1	0.1	0.1	0.1	0.1
Bouteloua eriopoda	85.2	75.9	82.0	81.0	78.1	69.1	69.0	72.1
Bouteloua gracilis	0.4	0.1	0.2	0.2	3.5	4.0	4.0	3.8
Enneapogon desvauxii	0.1	0.1	t	0.1	0.0	0.2	0.0	0.1
Erioneuron pulchellum	0.2	0.2	0.2	0.2	0.1	0.4	0.1	0.2
Hilaria mutica	0.0	0.1	0.4	0.2	1.6	0.7	0.1	0.8
Muhlenbergia arenacea	0.0	t	0.0	t	0.1	0.2	0.1	0.1
Muhlenbergia arenicola	5.8	7.2	5.8	6.3	3.2	4.2	4.5	4.0
Muhlenbergia porteri	0.0	0.0	0.0	0.0	1.8	0.2	1.8	1.3
Panicum hallii	t	0.0	0.0	t	t	0.0	0.0	t
Scleropogon brevifolius	0.2	0.1	0.1	0.1	1.9	1.2	1.6	1.6
Setaria leucopila	0.0	t	0.0	t	0.8	t	0.4	0.4
Sporobolus airoides	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.1
Sporobolus contractus	0.0	0.8	0.9	0.6	0.0	0.6	1.0	0.5
Sporobolus cryptandrus	3.3	3.2	3.4	3.3	0.5	1.7	2.7	1.6
Acourtia nana	0.3	0.6	0.2	0.4	0.1	0.5	0.1	0.2
Baileya multiradiata	t	0.0	0.0	t	t	0.0	0.0	t
Caesalpinia jamesii	0.0	t	0.0	t	0.0	0.0	0.0	0.0
Chaetopappa eriocoides	0.2	0.1	0.1	0.1	1.0	0.1	0.2	0.4
Croton pottsii	0.7	0.9	1.0	0.6	0.2	0.1	t	0.1
Dyssodia acerosa	0.0	0.0	0.1	t	0.0	0.0	0.3	0.1
Erigonum abertianum	0.0	0.0	0.1	t	0.0	0.0	0.0	0.0
Euphorbia lata	0.0	t	0.0	t	0.0	0.1	0.0	t
Evolvulus nuttalianus	0.0	t	0.0	t	0.0	0.0	0.0	0.0
Heliotropium greggii	0.0	0.0	0.0	0.0	0.0	0.1	0.0	t
Lepidium montanum	0.1	0.2	0.1	0.1	t	0.1	t	t
Lesquerella fendleri	0.0	0.0	0.0	0.0	0.0	0.0	0.1	t
Machaeranthera pinnatifida	0.0	0.0	t	t	0.0	t	0.0	t
Psilostrophe tagetina	0.0	0.1	0.2	0.1	0.0	0.0	t	t
Senna bauhinioides	0.0	0.1	0.0	t	0.0	0.0	0.0	0.0
Solanum elaeagnifolium	0.2	0.5	0.1	0.3	0.1	0.6	0.1	0.3
Sphaeralcea coccinea	0.2	0.4	0.4	0.3	0.1	0.3	0.1	0.2
Talinum aurantiacum	0.0	0.1	0.0	t	0.0	0.0	0.0	0.0
Tetraclea coulteri	t	0.1	t	0.1	0.0	0.2	t	0.1
Thymophylla acerosa	0.0	0.1	0.0	t	0.0	t	0.0	t
Zinna grandiflora	0.4	0.3	0.4	0.4	0.2	0.3	0.3	0.3
Aristida adscensionis	t	t	0.0	t	t	t	0.1	t
Chenopodium incanum	0.0	0.0	0.0	0.0	0.0	0.1	0.0	t
Descurainia pinnata	t	0.0	0.0	t	0.0	0.0	0.0	0.0
Linum aristatum	0.0	t	0.0	t	0.0	0.0	0.0	0.0
Salsola iberica	0.0	0.2	t	0.1	0.0	0.0	0.0	0.0
Shrubs	0.2	8.4	3.8	4.1	6.7	7.1	10.9	8.2
Succulents	2.2	0.6	0.5	1.1	t	8.0	1.7	3.2
Perennial grasses	95.5	87.6	93.2	92.1	91.8	82.6	86.2	86.9
Perennial forbs	2.1	3.3	2.5	2.6	1.5	2.2	1.1	1.6
Annual grasses	t	t	0.0	t	0.0	t	0.1	t
Annual forbs	t	0.2	t	0.1	0.0	0.1	0.0	t
Number of species	23	36	30	29.7	24	34	32	30.0
Total species				44				42

Note: Data are means (24 plots per site per date) of baseline (Feb 1998) and validation (Oct 1998 and Oct 1999) data collected from the same plots. Trace amounts (<0.05%) are indicated by a "t".

Table 3. Aboveground biomass (g/m^2) of the black grama grassland community at the Fort Bliss Otero Mesa study site.

Species/Lifeform	Last Burned 1986				Last Burned 1995			
	Feb 98	Oct 98	Oct 99	Mean	Feb 98	Oct 98	Oct 99	Mean
Ceratoides lanata	0.1	0.5	0.9	0.5	0.0	0.0	0.0	0.0
Condalia ericoides	0.0	0.0	0.7	0.2	0.0	0.0	0.0	0.0
Flourensia cernua	0.0	0.0	0.0	0.0	0.0	2.4	0.0	0.8
Gutierrezia sarothrae	0.1	5.6	4.4	3.4	0.1	0.5	0.3	0.3
Koberlina spinosa	0.0	0.0	0.0	0.0	0.0	1.6	0.3	0.6
Larrea tridentata	0.0	0.0	0.0	0.0	9.9	8.9	16.1	11.6
Prosopis glandulosa	0.0	0.0	0.1	t	0.0	0.0	0.0	0.0
Yucca elata	0.0	10.4	0.1	3.5	0.0	0.0	0.1	t
Opuntia imbricata	0.0	0.9	0.0	0.3	0.0	14.2	2.5	5.6
Opuntia macrocentra	0.0	0.0	0.0	0.0	t	0.8	0.0	0.3
Opuntia polyacantha	2.8	0.2	0.8	1.3	0.0	0.4	0.1	0.2
Aristida barbata	0.0	0.2	0.1	0.1	0.0	0.0	·0.3	0.1
Aristida purpurea	0.3	t	0.2	0.2	0.1	0.2	0.2	0.2
Bouteloua eriopoda	107.4	148.5	133.1	129.7	116.1	132.6	106.1	118.3
Bouteloua gracilis	0.5	0.1	0.4	0.3	5.5	7.7	6.2	6.5
Enneapogon desvauxii	0.1	0.1	t	0.1	0.0	0.3	0.0	0.1
Erioneuron pulchellum	0.3	0.3	0.3	0.3	0.1	0.8	0.2	0.4
Hilaria mutica	0.0	0.2	0.7	0.3	2.4	1.3	0.1	1.3
Muhlenbergia arenacea	0.0	t	0.0	t	0.1	0.4	0.2	0.2
Muhlenbergia arenicola	7.3	14.1	9.5	10.3	4.7	8.1	6.9	6.6
Muhlenbergia porteri	0.0	0.0	0.0	0.0	2.7	0.4	2.8	2.0
Panicum hallii	t	0.0	0.0	t	t	0.0	0.0	t
Scleropogon brevifolius	0.2	0.1	0.1	0.1	2.8	2.3	2.5	2.5
Setaria leucopila	0.0	t	0.0	t	1.2	t	0.6	0.6
Sporobolus airoides	0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.2
Sporobolus contractus	0.0	1.5	1.4	1.0	0.0	1.1	1.5	0.9
Sporobolus cryptandrus	4.2	6.3	5.6	5.4	0.8	3.2	4.2	2.7
Acourtia nana	0.4	1.1	0.4	0.6	0.1	1.0	0.1	0.4
Baileya multiradiata	t	0.0	0.0	t	t	0.0	0.0	t
Caesalpinia jamesii	0.0	t	0.0	t	0.0	0.0	0.0	0.0
Chaetopappa eriocoides	0.2	0.1	0.2	0.2	1.5	0.1	0.3	0.6
Croton pottsii	0.9	1.8	1.6	1.4	0.2	0.2	t	0.1
Dyssodia acerosa	0.0	0.0	0.1	t	0.0	0.0	0.5	0.2
Erigonum abertianum	0.0	0.0	0.1	t	0.0	0.0	0.0	0.0
Euphorbia lata	0.0	t	0.0	t	0.0	0.2	0.0	0.1
Evolvulus nuttalianus	0.0	t	0.0	t	0.0	0.0	0.0	0.0
Heliotropium greggii	0.0	0.0	0.0	0.0	0.0	0.1	0.0	t
Lepidium montanum	0.1	0.4	0.1	0.2	t	0.1	t	t
Lesquerella fendleri	0.0	0.0	0.0	0.0	0.0	0.0	0.1	t
Machaeranthera pinnatifida	0.0	0.0	t	t	0.0	t	0.0	t
Psilostrophe tagetina	0.0	0.1	0.3	0.1	0.0	0.0	t	t
Senna bauhinioides	0.0	0.2	0.0	0.1	0.0	0.0	0.0	0.0
Solanum elaeagnifolium	0.3	1.0	0.1	0.5	0.1	1.1	0.1	0.4
Sphaeralcea coccinea	0.3	0.7	0.6	0.5	0.1	0.5	0.2	0.3
Talinum aurantiacum	0.0	0.2	0.0	0.1	0.0	0.0	0.0	0.0
Tetraclea coulteri	t	0.1	t	t	0.0	0.3	t	0.1
Thymophylla acerosa	0.0	0.1	0.0	t	0.0	t	0.0	t
Zinna grandiflora	0.5	0.6	0.7	0.5	0.2	0.6	0.4	0.3
Aristida adscensionis	t	t	0.0	t	t	t	0.2	0.1
Chenopodium incanum	0.0	0.0	0.0	0.0	0.0	0.1	0.0	t
Descurainia pinnata	t	0.0	0.0	t	0.0	0.0	0.0	0.0
Linum aristatum	0.0	t	0.0	t	0.0	0.0	0.0	0.0
Salsola iberica	0.0	0.3	t	0.1	0.0	0.0	0.0	0.0
Shrubs	0.2	16.5	6.2	7.6	10.0	13.7	16.7	13.5
Succulents	2.8	1.1	0.8	1.6	t	15.4	2.6	6.0
Perennial grasses	120.3	171.4	151.4	147.7	136.5	158.4	132.4	142.4
Perennial forbs	2.7	6.4	4.0	4.4	2.2	4.2	1.7	2.7
Annual grasses	t	t	0.	t	0.0	t	0.2	0.1
Annual forbs	t	0.3	t	0.1	0.0	0.1	0.0	t
Total aboveground	126.1	195.7	162.5	161.4	148.7	191.8	153.7	164.7
Litter	22.1	24.7	23.6	23.5	30.1	31.8	37.2	33.0

Note: Data are means (24 plots per site per date) of baseline (Feb 1998) and validation (Oct 1998 and Oct 1999) data collected from the same plots. Trace amounts (<0.05 %) are indicated by a "t".

Effects of Water and Nitrogen Availability on Biomass

Results of the water and nitrogen availability treatments for the 1986-burned site are presented in Table 4, and in Table 5 for the 1995-burned site. Of the variables reported in Tables 4 and 5, most were for relatively minor species and had nonnormal statistical distributions. Therefore, parametric statistical tests, such as analysis of variance and t-tests, should not be applied to these variables. Eleven of the 38 variables in Table 4 and 13 of the 39 variables in Table 5 had normal distributions. Analysis of variance was applied to these variables to test for the significance of the differences in means due to the treatments and their interactions (Table 6).

The water treatment did not have a significant effect on the biomass of any of the variables at the 1986-burned site, but decreased the biomass of black grama 21% and total perennial grasses 17%, compared to control, at the 1995-burned site (Table 6). We attribute this decrease in black grama to increased competition from associated species; other species were more efficient users of the increased water than was black grama. Since black grama was the major grass species at the site (84% of perennial grass biomass, Table 3), total perennial grass biomass also showed a negative response to the water treatment, but at a slightly lower rate (81%). Creosotebush, sand muhly, bush muhly, burrograss, sand dropseed, and perhaps plains bristlegrass showed increases in biomass on the watered plots that were probably biologically significant. Competition from these species may have caused the decrease in black grama biomass.

There was an opposite response at the 1986-burned site (Table 5). Black grama biomass increased with watering, although this response was not quite significant at $P = 0.10$ ($P = 0.885$, Table 6), and the biomasses of sand muhly and sand dropseed did not increase. Creosotebush, bush muhly, and plains bristlegrass did not occur at this site, and burrograss was only a minor species. Black grama is not adapted to high-disturbance areas. The competing species are adapted to a much greater extent. Therefore, the differences in response patterns to increased water at the two sites may be more attributable to successional dynamics than moisture.

Table 4. Effects of water and nitrogen availability on aboveground biomass (g/m^2) on 1986-burned plots, Otero Mesa, Fort Bliss.

Species/Lifeform	Added Water	Control	High Nitrogen	Control)	Sucrose (low N)
Ceratoides lanata	0.86	0.87	0.40	0.00	2.32
Condalia eriocoides	0.00	1.45	2.17	0.00	0.00
Gutierrezia sarothrae	5.27	3.56	3.48	8.69	0.95
Prosopis glandulosa	0.00	0.10	0.00	0.00	0.15
Yucca elata	0.00	0.14	0.15	0.04	0.00
Opuntia polyacantha	1.64	0.00	2.45	0.00	0.00
Aristida fendleriana	0.29	0.08	0.18	0.13	0.26
Bouteloua eriopoda	143.87	122.33	140.13	134.21	124.95
Bouteloua gracilis	0.69	0.14	0.84	0.19	0.20
Enneapogon desvauxii	0.00	0.03	0.00	0.05	0.00
Erioneuron pulchellum	0.13	0.35	0.12	0.47	0.18
Hilaria mutica	0.00	1.48	0.00	0.00	2.20
Muhlenbergia arenicola	9.14	9.92	12.32	9.47	6.66
Scleropogon brevifolius	0.24	0.00	0.00	0.00	0.36
Sporobolus contractus	1.82	0.95	1.52	2.19	0.44
Sporobolus cryptandrus	5.50	5.69	6.37	7.42	2.93
Acourtia nana	0.18	0.58	0.11	0.48	0.57
Chaetopappa eriocoides	0.09	0.08	0.24	0.00	0.00
Croton pottsii	1.69	1.47	2.37	0.91	1.45
Dyssodia acerosa	0.21	0.00	0.16	0.00	0.15
Eriogonum abertianum	0.00	0.09	0.00	0.15	0.00
Lepidium montanum	0.21	0.00	0.13	0.06	0.13
Machaeranthera pinnatifida	0.03	0.00	0.04	0.00	0.00
Psilostrophe tagentina	0.44	0.15	0.32	0.38	0.21
Solanum elaegnifolium	0.07	0.19	0.14	0.00	0.17
Sphaeralcea coccinea	0.61	0.64	1.24	0.45	0.18
Tetraclea coulteri	0.02	0.02	0.00	0.03	0.03
Zinnia grandiflora	0.54	0.77	1.64	0.00	0.33
Aristida dissita	0.00	0.12	0.00	0.00	0.17
Salsola iberica	0.00	0.03	0.00	0.05	0.00
Shrubs	6.13	6.12	6.20	8.73	3.42
Succulents	1.64	0.00	2.45	0.00	0.00
Perennial grasses	161.68	140.97	161.48	154.13	138.18
Perennial forbs	4.09	3.99	6.39	2.46	3.22
Annual grasses	0.00	0.12	0.00	0.00	0.17
Annual forbs	0.00	0.03	0.00	0.05	0.00
Total	173.57	151.45	176.68	165.69	145.17
Litter	24.26	22.36	19.38	23.32	27.51

Note: Data are means of 12 plots for each water treatment and 8 plots for each nitrogen treatment.

Table 5. Effects of water and nitrogen availability on aboveground biomass (g/m^2) on 1995-burned plots, Otero Mesa, Fort Bliss.

Species/Lifeform	Added Water	Control	High Nitrogen	Control	Sucrose (low N)
Gutierrezia sarothrae	0.40	0.09	0.14	0.00	0.60
Koeberlinia spinosa	0.00	0.63	0.00	0.00	0.95
Larrea tridentata	17.61	14.56	17.65	15.35	15.26
Yucca elata	0.00	0.16	0.00	0.15	0.09
Opuntia imbricata	5.00	0.00	0.00	0.00	7.50
Opuntia polyacantha	0.00	0.22	0.33	0.00	0.00
Aristida purpurea	0.0	0.31	0.00	0.47	0.00
Bouteloua eriopoda	93.66	118.53	95.57	126.10	96.62
Bouteloua gracilis	4.39	7.94	7.51	4.72	6.26
Erioneuron pulchellum	0.15	0.24	0.41	0.18	0.00
Hilaria mutica	0.00	0.29	0.00	0.00	0.43
Muhlenbergia arenacea	0.44	0.15	0.40	0.20	0.05
Muhlenbergia arenicola	8.20	5.63	7.63	7.86	5.29
Muhlenbergia porteri	3.47	2.13	2.74	2.05	3.60
Scleropogon brevifolius	2.99	1.93	6.63	0.32	0.44
Setaria leucopila	1.25	0.03	1.91	0.00	0.00
Sporobolus airoides	0.00	1.15	1.73	0.00	0.00
Sporobolus contractus	0.92	2.16	0.11	2.46	2.04
Sporobolus cryptandrus	4.76	3.71	2.59	5.13	4.99
Acourtia nana	0.06	0.08	0.03	0.08	0.11
Chaetopapa ericoides	0.39	0.22	0.26	0.00	0.65
Croton pottsii	0.04	0.03	0.04	0.00	0.06
Dyssodia acerosa	0.43	0.55	0.87	0.00	0.60
Lepidium montanum	0.06	0.00	0.00	0.00	0.08
Lesquerella fendleri	0.10	0.00	0.00	0.00	0.15
Psilostrophe tagetina	0.07	0.00	0.00	0.11	0.00
Solanum elaeagnifolium	0.07	0.11	0.16	0.10	0.00
Sphaceralcea coccinea	0.16	0.24	0.28	0.14	0.18
Tetraclea coulteri	0.03	0.00	0.00	0.00	0.04
Zinnia grandiflora	0.61	0.14	0.60	0.38	0.14
Aristida adscensionis	0.47	0.00	0.70	0.00	0.00
Aristida dissita	0.00	0.64	0.79	0.00	0.16
Shrubs	18.01	15.44	17.79	15.50	16.90
Succulents	5.00	0.22	0.33	0.00	7.50
Perennial grasses	120.23	144.20	127.23	149.49	119.72
Perennial forbs	2.02	1.37	2.24	0.81	2.01
Annual grasses	0.47	0.64	1.49	0.00	0.16
Total aboveground	145.58	161.88	149.11	165.81	146.26
Litter	36.45	38.00	37.78	41.61	32.78

Note: Values are means of 12 plots for each water treatment and 8 plots on each nitrogen treatment, Oct-Nov 1999.

Response to nitrogen availability was significant for three variables at the 1986-burned site and two variables at the 1995-burned site (Table 6). At the 1986-burned site, sand muhly biomass decreased as nitrogen availability decreased, as did sand dropseed biomass at the lowest nitrogen level. Perennial forb biomass, primarily globemallow (*Sphaeralcea coccinea*) and plains zinnia (*Zinnia*

grandiflora), increased with the high nitrogen treatment. At the 1995-burned site, black grama biomass decreased in response to both high and low nitrogen availability and burrograss biomass was increased by the high nitrogen treatment.

There were no significant interactions between the water and nitrogen treatments (WxN) at either site (Table 6). This indicates that the ecological responses to each of these factors is consistent in relation to the other factor.

Table 6. Summary of analysis of variance results on the effects of water and nitrogen availability treatments on biomass (g/m^2) data from Fort Bliss, October 1999.

Variable	F-ratio			Probability		
	Water	Nitrogen	WxN	Water	Nitrogen	WxN
Burned 1986						
Bouteloua eriopoda	2.74	0.46	1.35	0.115	0.637	0.284
Bouteloua gracillis	0.87	0.53	1.07	0.362	0.596	0.364
Muhlenbergia arenicola	0.14	2.63	0.78	0.710	0.100	0.926
Sporobolus contractus	0.38	0.52	0.37	0.545	0.602	0.699
Sporobolus cryptandrus	0.02	2.96	1.08	0.905	0.077	0.362
Croton pottsii	0.04	0.56	0.32	0.852	0.582	0.732
Shrubs	0.01	0.38	0.48	0.932	0.688	0.625
Perennial grasses	2.78	1.23	1.64	0.113	0.316	0.222
Perennial forbs	0.00	3.52	0.11	0.989	0.051	0.895
Total aboveground biomass	2.61	1.82	1.58	0.123	0.190	0.234
Litter	0.56	1.93	0.59	0.466	0.174	0.563
Burned 1995						
Larrea tridentata	0.31	0.08	0.14	0.585	0.922	0.873
Bouteloua eriopoda	5.42	3.51	0.35	0.032	0.052	0.711
Bouteloua gracilis	1.66	0.34	1.69	0.214	0.715	0.213
Muhlenbergia arenicola	1.28	0.53	0.60	0.273	0.598	0.559
Scleropogon brevifolius	0.31	4.76	0.58	0.585	0.022	0.572
Sporobolus contractus	1.12	1.54	1.50	0.305	0.242	0.249
Sporobolus cryptandrus	0.38	0.94	0.46	0.543	0.409	0.637
Shrubs	0.23	0.06	0.13	0.641	0.941	0.881
Perennial grasses	4.48	2.29	0.23	0.049	0.131	0.799
Perennial forbs	0.48	0.95	1.34	0.498	0.405	0.287
Total aboveground biomass	1.69	0.95	0.76	0.210	0.406	0.484
Litter	0.03	0.42	0.17	0.855	0.662	0.849

Effects of Water and Nitrogen Availability on Species Composition

The water treatment did not significantly affect the relative biomass of any species or lifeform at the 1986-burned site (Table 7). At the 1995-burned site, the water treatment decreased the relative biomass of perennial grasses (Tables 7 and 8). This decrease was the result of a decrease in black grama (Table 8), which was probably caused by increased competition from creosotebush and earlier-seral grasses.

Nitrogen availability did not affect the relative biomass of any species or lifeform at the 1986-burned site (Table 7), but greatly increased the relative biomass of burrograss at the 1995-burned site (Table 8). There were no significant interactions between the water and nitrogen availability treatments (Table 7).

Table 7. Summary of analysis of variance results on the effects of water and nitrogen availability treatments on species composition (% relative biomass) data from Fort Bliss, October 1999.

Variable	F-ratio			Probability		
	Water	Nitrogen	WxN	Water	Nitrogen	WxN
Burned 1986						
Bouteloua eriopoda	1.19	1.57	0.14	0.290	0.235	0.874
Bouteloua gracilis	0.78	0.46	1.12	0.389	0.636	0.348
Muhlenbergia arenicola	0.46	0.77	0.22	0.505	0.480	0.804
Sporobolus contractus	0.00	0.74	0.59	0.997	0.490	0.563
Sporobolus cryptandrus	0.84	2.57	0.70	0.372	0.105	0.511
Croton pottsii	0.00	0.35	0.48	0.992	0.707	0.627
Shrubs	0.22	0.15	0.40	0.642	0.859	0.678
Perennial grasses	0.05	0.55	0.13	0.825	0.586	0.879
Perennial forbs	0.12	2.11	0.32	0.729	0.150	0.727
Burned 1995						
Larrea tridentata	0.82	0.14	0.04	0.377	0.872	0.965
Bouteloua eriopoda	2.61	1.80	0.17	0.124	0.194	0.842
Bouteloua gracilis	1.07	0.71	1.77	0.315	0.504	0.199
Muhlenbergia arenicola	2.23	0.57	0.63	0.152	0.577	0.545
Scleropogon brevifolius	0.70	6.14	1.09	0.412	0.009	0.358
Sporobolus contractus	1.55	1.48	1.22	0.229	0.254	0.318
Sporobolus cryptandrus	0.32	0.76	0.73	0.580	0.482	0.497
Shrubs	0.71	0.21	0.03	0.411	0.817	0.968
Perennial grasses	3.15	1.39	0.98	0.093	0.274	0.396
Perennial forbs	1.28	1.18	1.30	0.272	0.329	0.297

Table 8. Effects of water and nitrogen availability on species composition (% relative biomass) on 1995-burned plots, Otero Mesa, Fort Bliss.

Species/Lifeform	Added Water	Control	High Nitrogen	Control	Sucrose (low N)
Gutierrezia sarothrae	0.32	0.08	0.11	0.00	0.49
Koeberlinia spinosa	0.00	0.43	0.00	0.00	0.44
Larrea tridentata	12.42	8.81	11.80	9.37	10.93
Yucca elata	0.00	0.12	0.00	0.11	0.07
Opuntia imbricata	3.02	0.00	0.00	0.00	4.38
Opuntia polyacantha	0.00	0.14	0.21	0.00	0.00
Aristida fendleriana	0.00	0.22	0.00	0.33	0.00
Bouteloua eriopoda	64.85	72.93	64.37	75.44	66.86
Bouteloua gracilis	3.19	5.00	5.35	2.75	4.16
Erioneuron pulchellum	0.13	0.17	0.28	0.09	0.00
Hilaria mutica	0.00	0.18	0.00	0.00	0.27
Muhlenbergia arenacea	0.17	0.09	0.24	0.10	0.04
Muhlenbergia arenicola	5.74	3.46	5.08	5.27	3.45
Muhlenbergia porteri	1.91	1.40	1.68	1.03	2.25
Scleropogon brevifolius	2.16	1.19	4.56	0.16	0.28
Setaria leucopila	0.78	0.01	1.19	0.00	0.00
Sporobolus airoides	0.00	0.52	0.78	0.00	0.00
Sporobolus contractus	0.51	1.38	0.09	1.43	1.31
Sporobolus cryptandrus	3.11	2.49	1.84	3.31	3.26
Acourtia nana	0.04	0.06	0.02	0.05	0.07
Chaetopappa ericoides	0.27	0.15	0.17	0.00	0.46
Croton pottsii	0.03	0.02	0.03	0.00	0.05
Dyssodia acerosa	0.25	0.25	0.40	0.00	0.33
Lepidium montanum	0.05	0.00	0.00	0.00	0.07
Lesquerella fendleri	0.06	0.00	0.00	0.00	0.08
Psilostrophe tagentina	0.05	0.00	0.00	0.08	0.00
Solanum elaegnifolium	0.05	0.06	0.10	0.07	0.00
Sphaeralcea coccinea	0.12	0.18	0.22	0.09	0.14
Tetraclea coulteri	0.02	0.00	0.02	0.00	0.01
Zinnia Grandiflora	0.45	0.07	0.83	0.23	0.13
Aristida adscensionis	0.31	0.00	0.46	0.00	0.00
Aristida dissita	0.00	0.47	0.58	0.00	0.13
Total shrubs	12.74	9.44	11.91	9.48	11.93
Total succulents	3.02	0.14	0.21	0.00	4.38
Total perennial grasses	84.89	89.04	85.46	89.91	81.88
Total perennial forbs	1.39	0.79	1.79	0.52	1.34
Total annual grasses	0.31	0.47	1.04	0.00	0.13
Total annual forbs	0.00	0.00	0.00	0.00	0.00

Note: Data are means of 12 plots per water treatment and 8 plots per nitrogen treatment, Sep-Oct 1999.

Discussion of Effects of Water and Nitrogen Availability

The water and nitrogen availability treatments have been applied for only 1 year. That is a short time for ecological responses to be manifested, especially since the application rates were relatively low. Mid- and late-seral grasslands in

eastern Colorado, for example, required 3 to 4 years to show statistically significant responses to nitrogen availability (Paschke et al. 2000). However, ecological responses were recorded, some of which were statistically significant, and the patterns of these responses are consistent with expectations based on ecological theory.

Mean black grama biomass was 18% greater on 1986-burned plots that received 8% more water than control plots (Table 4). Although this difference was not statistically significant ($P = 0.115$), it may be significant biologically because of increased potential production over time. Conversely, the water treatment decreased black grama biomass on the 1995-burned plots. A possible explanation for this pattern is related to successional status. Black grama comprised 81% of the composition at the 1986-burned site, but only 72% at the 1995-burned site. On the 1986-burned site, black grama may have been abundant enough, or physiologically healthy enough, to out-compete most of the species competing for the supplemental water. In support of this, sand muhly and sand dropseed, two of the primary competing species, did not increase on the watered plots on the 1986-burned site, but did increase on the 1995-burned site. On the 1995-burned plots, the competing species, which are faster-growing species, may have been too abundant for the black grama to successfully compete. Specifically, black grama is not as well-adapted to fire as are many of the associated species in this desert grassland. The black grama at the more recently burned site may not have sufficiently recovered physiologically from the fire disturbance to be as competitive as the black grama plants at the 1986-burned site.

This raises two important management points. First, prescribed burning regimes in this grassland should be based on the ecophysiological requirements of black grama, the historically dominant native species. Second, patterns of response to environmental stressors in these grasslands will be influenced by time since disturbance. For example, wet years immediately following fire may result in a longer dominance of the site by earlier-seral species such as sand muhly, sand dropseed, and burrograss, and a slower recovery by black grama than if the years following fire were average or perhaps even dry. Therefore, the timing of wet years in relation to disturbance events may be very important in determining successional patterns and rates of secondary succession.

On the 1986-burned site, the relative biomass of black grama increased as nitrogen availability decreased (Table 9). This is the typical response of late-seral species to nitrogen availability (McLendon and Redente 1992, 1994, Paschke et al. 2000). Sand muhly and sand dropseed decreased in abundance, which is typical of earlier-seral species. However, on the 1995-burned site, a number of species commonly considered as late-seral species in this grassland (creosote-

bush, black grama, blue grama, bush muhly) showed no compositional pattern related to the nitrogen availability gradient. This suggests that some other ecological factor is controlling successional dynamics at this time at this site.

Table 9. Effects of water and nitrogen availability on species composition (% relative biomass) on 1986-burned plots, Otero Mesa, Fort Bliss.

Species/Lifeform	Water	Control	Nitrogen	Control	Scrose
Ceratoides lanata	0.55	0.74	0.19	0.00	1.68
Condalia eriocoides	0.00	0.89	1.34	0.00	0.00
Gutierrezia sarothrae	2.32	2.16	1.90	4.17	0.64
Prosopis glandulosa	0.04	0.09	0.00	0.07	0.13
Yucca elata	0.00	0.07	0.07	0.03	0.00
Opuntia polyacantha	0.73	0.00	1.09	0.00	0.00
Aristida fendleriana	0.18	0.05	0.10	0.08	0.17
Bouteloua eriopoda	83.18	79.88	79.10	80.23	85.28
Bouteloua gracilis	0.39	0.09	0.47	0.11	0.15
Enneapogon desvauxii	0.00	0.04	0.00	0.06	0.00
Erioneuron pulchellum	0.09	0.36	0.09	0.42	0.12
Hilaria mutica	0.00	1.01	0.00	0.00	1.52
Muhlenbergia arenicola	5.78	6.88	7.51	6.39	5.07
Scleropogon brevifolius	0.19	0.00	0.00	0.00	0.24
Sporobolus contractus	1.04	1.04	0.72	2.00	0.40
Sporobolus cryptandrus	2.98	3.79	3.63	4.48	2.07
Acourtia nana	0.10	0.44	0.05	0.39	0.48
Chaetopappa eriocoides	0.08	0.15	0.14	0.13	0.09
Croton pottsii	1.00	0.97	1.41	0.63	0.92
Dyssodia acerosa	0.15	0.00	0.13	0.00	0.10
Eriogonum abertianum	0.00	0.11	0.00	0.16	0.00
Lepidium montanum	0.14	0.00	0.06	0.04	0.12
Machaeranthera pinnatifida	0.01	0.00	0.02	0.00	0.00
Psilostrophe tagetina	0.26	0.14	0.18	0.40	0.18
Solanum elaegnifolium	0.06	0.15	0.09	0.09	0.14
Sphaeralcea coccinea	0.38	0.42	0.93	0.30	0.11
Tetraclea coulteri	0.01	0.02	0.00	0.02	0.03
Zinnia grandiflora	0.33	0.44	0.93	0.00	0.23
Aristida dissita	0.00	0.08	0.00	0.00	0.12
Salsola iberica	0.00	0.03	0.00	0.05	0.00
Total shrubs	2.91	3.95	3.50	4.27	2.45
Total succulents	0.73	0.00	1.09	0.00	0.00
Total perennial grasses	93.83	93.14	91.62	93.77	95.02
Total perennial forbs	2.52	2.84	3.94	2.16	2.40
Total annual grasses	0.00	0.08	0.00	0.00	0.12
Total annual forbs	0.00	0.03	0.00	0.05	0.00

Note: Data are means of 12 plots per water treatment and 8 plots per nitrogen treatment, Sep-Oct 1999.

Little Bluestem Grassland, Fort Hood

The Fort Hood site was dominated by little bluestem (51%), with tall dropseed (*Sporobolus asper*), seep muhly (*Muhlenbergia reverchonii*), sumpweed (*Iva xanthifolia*), broomweed (*Amphiachyris drancunculoides*), King Ranch bluestem (*Bothriochloa ischaemum*), hairy grama (*Bouteloua hirsuta*), silver bluestem (*Bothriochloa saccharoides*), prairie bluets (*Hedyotis nigricans*), and Texas wintergrass (*Stipa leucotricha*) important secondary species (Table 10). A total of 56 species were encountered in the plots, 18 of which were perennial grasses, 30 were perennial forbs, and 8 were annual forbs. Perennial grasses comprised an average of 80% of the biomass, perennial forbs 8%, and annual forbs 11%. Annual standing crop biomass varied from 103 to 208 g/m^2.

Effects of Water and Nitrogen Availability on Biomass

The significance of the water and nitrogen treatments were tested for 15 biomass variables (Table 11). The water treatment was not significant for any of the 15 variables. This was probably because only one water application was made, and this application totaled only 4% of the average annual precipitation for the site.

The nitrogen availability treatment had a significant effect on four variables (Table 11). Biomass of both tall dropseed (*Sporobolus asper*) and prairie bluets (*Hedyotis nigricans*) increased as nitrogen availability increased, as did perennial forb biomass and total aboveground biomass (Table 12). Biomass of a number of other species, including little bluestem (*Schizachyrim scoparium*), increased as nitrogen availability increased, but their increases were not statistically significant because of variability among plots. There were no significant interactions between the water and nitrogen availability treatments (Table 11).

Table 10. Aboveground biomass (g/m^2), ash-free root biomass (g/m^2), and species composition (% relative biomass) on the bluestem prairie community study site, Fort Hood.

Species/Lifeform	Biomass				Composition			
	Mar 98	Nov 98	Oct 99	Mean	Mar 98	Nov 98	Oct 99	Mean
Argrostis hiemalis	0.0	0.0	0.3	0.1	0.0	0.0	0.2	0.1
Aristida purpurea	0.3	t	1.4	0.6	0.3	t	0.0	0.1
Bothriochloa ischaemum	0.0	9.1	5.0	4.7	0.0	8.9	2.5	3.8
Bothriochloa saccharoides	4.0	1.0	1.4	2.1	6.4	0.9	0.6	2.6
Bouteloua curtipendula	0.0	3.3	3.7	2.3	0.0	4.0	2.0	2.0
Bouteloua gracilis	0.0	0.2	0.0	0.1	0.0	0.3	0.0	0.1
Bouteloua hirsuta	5.9	0.5	1.0	2.5	10.2	0.4	0.6	3.7
Boutelous rigidiseta	0.0	t	0.0	t	0.0	t	0.0	t
Buchloe dactyloides	t	0.1	0.2	0.1	t	0.1	0.1	0.1
Dichanthelium oligosanthes	0.1	t	0.0	t	0.1	t	0.0	t
Eragrostis elliotii	0.0	0.1	0.0	t	0.0	0.1	0.0	t
Muhlenbergia reverchonii	6.3	5.7	5.5	5.8	7.6	4.7	2.2	4.8
Panicum hallii	0.0	0.1	0.0	t	0.0	0.1	0.0	t
Panicum obtusum	0.0	0.1	0.0	t	0.0	t	0.0	t
Schizachyrium scoparium	36.0	52.9	99.6	62.8	54.5	51.2	47.7	51.1
Sorghastrum nutans	0.0	0.4	2.0	0.8	0.0	0.5	1.2	0.6
Sporobolus asper	0.0	14.4	32.9	15.8	0.0	15.1	16.4	10.5
Stipa leucotricha	2.1	2.4	5.2	3.2	3.0	2.2	2.3	2.5
Allium sp.	t	t	0.0	t	t	t	0.0	t
Anemone heterophylla	0.5	0.0	0.0	0.2	0.8	0.0	0.0	0.2
Asclepias asperula	0.0	t	0.0	t	0.0	t	0.0	t
Aster ericoides	0.2	0.4	1.8	0.8	0.6	0.3	0.9	0.6
Carex microdonta	3.0	1.7	2.5	2.4	4.5	1.7	1.1	2.4
Dacus carota	t	0.0	0.0	t	0.1	0.0	0.0	t
Eleocharis acutisquamata	t	0.0	0.0	t	t	0.0	0.0	t
Eriodium texanum	t	0.0	0.0	t	t	0.0	0.0	t
Gillardia pulchella	0.0	0.0	t	t	0.0	0.0	t	t
Hedoma drummondii	0.0	0.0	t	t	0.0	0.0	t	t
Hedyotis nigricans	1.0	0.4	12.2	4.5	1.4	0.4	6.2	2.7
Hymenoxys scaposa	0.3	t	0.0	0.1	0.4	t	0.0	0.1
Krameria lanceolata	0.0	0.0	0.3	0.1	0.0	0.0	0.2	0.1
Liatris mucronata	0.0	t	0.5	0.2	0.0	t	0.2	0.1
Melampodium leucanthum	0.0	t	t	t	0.0	t	t	t
Neptunia lutea	0.0	0.1	t	t	0.0	0.2	t	0.1
Monarda sp.	0.0	0.0	0.1	t	0.0	0.0	0.1	t
Nothoscordum bivalve	0.1	0.1	0.0	0.1	0.1	0.1	0.0	0.1
Oenothera sp.	t	0.0	0.0	t	0.1	0.0	0.0	t
Oxalis sp.	t	0.0	0.0	t	t	0.0	0.0	t
Phyla nodiflora	0.7	3.2	1.2	1.7	1.2	2.6	0.6	1.5
Phyllanthus polygonoides	t	0.1	0.0	t	t	0.1	0.0	t
Ratibida columnaris	0.1	0.0	0.1	0.1	0.1	0.0	0.1	0.1
Scutellaria sp.	0.1	0.0	0.0	t	0.1	0.0	0.0	t
Sida filicaulis	0.0	0.2	t	0.1	0.0	0.2	t	0.1
Sisyrinchuim sp.	0.1	0.0	0.0	t	0.2	0.0	0.0	0.1
Similax bona-nox	0.0	t	0.0	t	0.0	t	0.0	t
Taraxacum officinale	t	0.0	0.0	t	t	0.0	0.0	t
Tragia ramosa	0.0	0.3	t	0.1	0.0	0.3	t	0.1
Verbena neomexicana	t	t	0.0	t	t	t	0.0	t
Ambrosia artemisiifolia	0.0	0.6	0.8	0.5	0.0	0.6	0.3	0.3
Amphiachyris drancunculoides	5.5	1.2	4.7	3.8	8.2	1.1	2.4	3.9
Croton monanthogynus	0.0	0.1	0.2	0.1	0.0	0.1	0.1	0.1
Eryngynum leavenworthii	0.0	0.1	0.7	0.3	0.0	0.1	0.5	0.2
Euphorbia nutans	0.0	0.1	0.0	t	0.0	0.1	0.0	t
Evax prolifera	t	0.0	0.1	t	t	0.0	0.1	t
Iva xanthifolia	0.0	4.0	24.2	9.4	0.0	3.6	11.6	5.1
Plantago rhodosperma	0.1	0.1	0.1	0.1	0.2	0.1	t	0.1
Perennial grasses	54.7	90.3	158.2	101.1	82.1	88.5	75.8	80.4
Perennial forbs	6.1	6.5	18.7	10.4	9.6	5.9	9.4	8.3
Annual forbs	5.6	6.2	30.8	14.2	8.4	5.7	14.8	11.3
Total aboveground roots	66.7	102.9	207.7	125.8				
Litter	102.3	52.0	49.7	68.0				
Cow dung	22.7	17.5	23.1	21.1				

Note: Values are means (24 plots per site per date) of baseline (Mar 1998) and validation (Nov 1998 and Oct 1999) data collected from the same plots. Trace amounts (<0.05 %) are indicated by a "t".

Table 11. Summary of analysis of variance results on the effects of water and nitrogen availability treatments on species composition (% relative biomass) and biomass (g/m^2) data from Fort Hood, October 1999.

Variable	F-ratio			Probability		
	Water	Nitrogen	WxN	Water	Nitrogen	WxN
Composition						
Bothriochloa saccharoides	1.24	1.40	0.97	0.281	0.272	0.399
Bouteloua curtipendula	0.12	1.52	1.78	0.739	0.245	0.331
Schizachyrium scoparium	0.44	0.01	0.11	0.518	0.986	0.899
Sporobolus asper	0.17	0.57	0.38	0.685	0.576	0.690
Stipa leucotricha	0.05	1.32	0.58	0.834	0.291	0.572
Aster ericoides	1.80	0.50	1.20	0.196	0.615	0.324
Hedyotis nigricans	0.00	1.21	1.16	0.953	0.323	0.335
Amphiachyris dracunculoides	0.80	1.00	0.35	0.384	0.389	0.710
Iva xanthifolia	1.43	0.04	1.00	0.247	0.964	0.389
Perennial grasses	2.20	0.06	0.01	0.155	0.941	0.991
Perennial forbs	0.02	1.11	0.81	0.899	0.352	0.462
Annual forbs	1.21	0.36	0.62	0.286	0.706	0.551
Biomass						
Bothriochloa saccharoides	1.10	1.67	0.81	0.308	0.216	0.462
Bouteloua curtipendula	0.11	0.16	1.28	0.747	0.858	0.303
Schizachyrium scoparium	0.50	0.97	0.24	0.490	0.400	0.789
Sporobolus asper	0.00	4.61	0.48	0.991	0.024	0.625
Stipa leucotricha	0.01	0.86	0.52	0.947	0.439	0.601
Aster eriocoides	1.48	0.66	1.84	0.239	0.530	0.187
Hedyotis nigricans	0.24	3.63	1.63	0.629	0.047	0.223
Amphiachyris dracunculoides	1.81	0.19	0.54	0.195	0.827	0.590
Iva xanthifolia	0.73	0.10	0.17	0.403	0.906	0.846
Perennial grasses	0.22	2.38	0.32	0.645	0.125	0.732
Perennial forbs	0.06	4.37	0.75	0.804	0.028	0.485
Annual forbs	1.00	0.07	0.21	0.330	0.935	0.815
Total aboveground	0.03	2.65	0.10	0.876	0.098	0.906
Roots	0.15	0.13	0.07	0.705	0.878	0.936
Litter	0.39	0.33	0.18	0.541	0.724	0.836

Table 12. Effects of water and nitrogen availability on aboveground- and belowground biomass (g/m^2) on the bluestem prairie study site, Fort Hood.

Species/Lifeform	Added Water	Control	High Nitrogen	Control	Sucrose (low N)
Agrostis hiemalis	0.00	0.65	0.00	0.97	0.00
Artistida purpurea	1.90	0.89	0.76	0.65	2.78
Bothriochloa ischaemum	5.62	4.32	5.71	1.86	7.34
Bothriochloa saccharoides	1.87	0.92	2.14	1.79	0.24
Bouteloua curtipendula	3.53	3.94	3.34	3.69	4.18
Bouteloua hirstuta	0.95	1.03	0.75	1.41	0.82
Buchloe dactyloides	0.14	0.17	0.08	0.14	0.25
Muhlenbergia reverchonii	6.34	4.63	6.27	7.37	2.82
Schizachyrium scoparium	93.98	105.25	113.28	99.50	86.06
Sorghastrum nutans	1.80	2.24	3.56	1.24	1.27
Sporobolus asper	32.96	32.90	39.41	35.86	23.54
Stipa leucotricha	5.10	5.29	3.43	7.58	4.57
Aster ericoides	2.24	1.38	1.74	2.33	1.35
Carex microdonta	2.54	2.41	4.89	1.43	1.11
Gaillardia pulchella	0.00	0.09	0.00	0.00	0.13
Hedeoma drummondii	0.07	0.00	0.11	0.00	0.00
Hedyotis nigricans	13.01	11.43	18.01	11.04	7.61
Iva xanthifolia	28.30	20.12	26.75	24.34	21.55
Krameria lanceolata	0.53	0.07	0.00	0.90	0.00
Liatris mucronata	0.04	.97	0.51	0.11	0.90
Melampodium leucanthum	0.02	0.00	0.03	0.00	0.00
Monarda sp.	0.00	0.26	0.09	0.30	0.00
Neptunia lutea	0.00	0.02	0.00	0.00	0.03
Phyla nodiflora	0.84	1.54	0.85	2.31	0.40
Ratibida columnaris	0.00	0.10	0.00	0.00	0.14
Sida filicaulis	t	0.01	0.01	0.00	0.01
Tragia ramosa	0.00	t	0.00	0.00	0.01
Bromus japonicus	0.00	0.03	0.00	0.00	0.04
Ambrosia artemisiifolia	1.21	0.30	1.15	0.30	0.82
Amphiascyris drancunculoides	5.98	3.32	4.45	4.01	5.47
Croton monanthogynus	0.15	0.17	0.40	0.01	0.07
Eryngynum leavenworthii	0.06	1.23	0.36	0.25	1.33
Evax prolifera	0.01	0.10	0.00	0.02	0.15
Plantago rhodosperma	0.10	0.10	0.18	0.12	0.01
Perennial grasses	154.19	162.23	178.73	162.06	133.87
Perennial forbs	47.59	38.40	52.99	42.76	33.24
Annual grasses	0.00	0.03	0.00	0.00	0.04
Annual forbs	7.51	5.22	6.54	4.71	7.85
Total aboveground	209.30	205.88	238.29	209.50	174.99
Root biomass (0-20 cm)	216.42	235.67	232.75	237.25	208.13
Litter	46.27	53.06	45.40	55.76	47.85
Cow dung	23.37	22.83	20.44	40.24	8.62

Note: Values are means of 12 plots per water treatment and 8 plots per nitrogen treatment, October 1999. Trace amounts (<0.05 %) are indicated by a "t".

Effects of Water and Nitrogen Availability on Species Composition

There were no significant effects of water or nitrogen on the relative biomass of any of the 12 variables tested (Table 11). However, several of the variables displayed patterns that suggest they may become significant in 2 to 3 years.

The water treatment increased relative biomass of annual forbs and decreased relative biomass of perennial grasses (Table 13). The water treatment also decreased the relative biomass of little bluestem, tall dropseed, Indiangrass (*Sorghastrum nutans*), and sideoats (*Bouteloua curtipendula*). These are all midgrass or tallgrass species that are mid- or late-seral species in this community (Smiens 1994). The water treatment increased the relative biomass of seep muhly, purple threeawn (*Aristida purpurea*), heath aster (*Aster ericoides*), littletooth sedge (*Carex microdonta*), broomweed, and seepweed. These are early-seral or wetland species.

This is the same pattern that occurred on the 1995-burned site at Fort Bliss (i.e., early-seral species increase and late-seral species decrease). The ecological factor is probably the same. Early-seral species have greater potential for rapid uptake of belowground resources that suddenly become available, such as pulses of soil moisture and soil nitrogen (McLendon and Redente 1994). This is a primary competitive strategy in early-seral species (Redente et al. 1992).

However, response patterns in relation to nitrogen availability were opposite to those expected from successional theory. A decrease in nitrogen availability should increase the composition of late-seral species and decrease the composition of early-seral species (McLendon and Redente 1991, 1992, Paschke et al. 2000). Instead, the low available nitrogen treatment decreased the relative biomass of little bluestem and tall dropseed, and increased the relative biomass of broomweed and seepweed (Table 13).

Table 13. Effects of water and nitrogen availability on species composition (% relative biomass) on the bluestem prairie study site, Fort Hood.

Species/Lifeform	Added Water	Control	High Nitrogen	Control	Sucrose (low N)
Agrostis hiemalis	0.00	0.29	0.00	0.44	0.00
Aristida purpurea	0.95	0.77	0.40	0.30	1.89
Bothriochloa ischaemum	2.55	2.40	2.21	0.91	4.31
Bothriochloa saccharoides	0.85	0.36	0.78	0.93	0.10
Bouteloua curtipendula	1.88	2.13	1.32	1.85	2.84
Bouteloua hirsuta	0.47	0.65	0.40	0.69	0.59
Buchloe dactyloides	0.09	0.07	0.03	0.07	0.14
Muhlenbergia reverchonii	2.40	1.94	1.92	3.32	1.27
Schizachyrium scoparium	45.72	49.61	47.93	48.08	46.97
Sorghastrum nutans	1.06	1.25	1.95	0.58	0.94
Sporobolus asper	15.83	16.90	17.48	17.21	14.41
Stipa leucotricha	2.22	2.44	1.28	3.33	·2.38
Aster ericoides	1.09	0.64	0.67	1.12	0.87
Carex microdonta	1.31	0.92	2.00	0.71	0.63
Gaillardia pulchella	0.00	0.03	0.00	0.00	0.05
Hedoma drummondii	0.02	0.00	0.03	0.00	0.00
Hedyotis nigricans	6.28	6.17	8.25	5.32·	5.10
Krameria lanceolata	0.29	0.04	0.00	0.48	0.00
Liatris mucronata	0.02	0.45	0.20	0.05	0.46
Melampodium leucanthum	0.01	0.00	0.02	0.00	0.00
Monarda sp.	0.00	0.12	0.03	0.15	0.00
Netunia lutea	0.00	0.02	0.00	0.00	0.03
Phyla nodiflora	0.41	0.70	0.26	1.18	0.24
Ratibida columnaris	0.00	0.09	0.00	0.00	0.14
Sida fillicaulis	t	0.01	t	0.00	0.01
Tragia ramosa	0.00	t	0.00	0.00	0.01
Bromus japonicus	0.00	0.01	0.00	0.00	0.01
Ambrosia artemisiifolia	0.53	0.13	0.49	0.13	0.36
Amphiachyris drancunculoides	2.89	1.87	1.68	1.89	3.53
Croton monathogynus	0.07	0.10	0.19	t	0.06
Eryngynum leavenworthii	0.03	1.02	0.20	0.12	1.26
Evax prolifera	0.01	0.09	0.00	0.01	0.14
Iva xanthifolia	12.87	8.75	10.17	10.98	11.28
Plantago rhodsperma	0.05 ·	0.04	0.07	0.06	0.01
Perennial grasses	74.02	78.81	75.70	77.71	75.84
Perennial forbs	9.43	9.19	11.46	9.01	7.54
Annual grasses	0.00	0.01	0.00	0.00	0.01
Annual forbs	16.45	12.00	12.80	13.19	16.64
Number of species	27	32	26	25	30

Note: Values are means of 12 plots per water treatment and 8 plots per nitrogen treatment, Oct 1999. Trace amounts (<0.05 %) are indicated by a "t".

5 Simulation Results and Discussion

Black Grama Grassland, Fort Bliss

Selection of Species and Parameterization of EDYS

The number of plant species included in an EDYS simulation is flexible and is specified by the user. Regardless of the number of species selected, the user-defined vegetation "suite" remains a simplified representation of the actual plant community, since some species remain excluded. To account for overall community dynamics (e.g., total aboveground biomass), the ecological contribution of the species not specifically included in the model must somehow be accounted for. This is accomplished in EDYS by using composite species. In EDYS, a composite species consists of a major species plus those minor species most ecologically similar to the respective major species. For example, the composite *Muhlenbergia arenicola* includes *M. arenicola* plus *M. arenacea* and *M. porteri* (Table 14). The composite *Sporobolus cryptandrus* consists of *Sporobolus cryptandrus* plus four other species.

Eight composite species were included in the simulations of the black grama grassland: snakeweed (*Guitierrezia sarothrae* [GUSH]), creosotebush (*Larrea tridentate* [LATR]), black grama (*Bouteloua eripoda* [BOER]), blue grama (*Bouteloua gracilis* [BOGR]), sand muhly (*Muhlenbergia arenicola* [MUAR], sand dropseed (*Sporobolus cryptandrus* [SPCR]), purple threeawn (*Aristida purpurea* [ARPU]), and croton (*Croton pottsii* [CRPO]). These 8 species comprised 94% of the overall aboveground biomass on the February 1998 sampling date and 91% averaged over the three sampling dates (February 1998, October 1998, and October 1999). A total of 22 other species contributed the remaining 6% of aboveground biomass in February 1998 and 45 other species contributed the remaining 9% of aboveground biomass overall. Only one other species, cholla, would have been included as a major species (> 1% relative biomass, averaged over the two sites) had the data from the three sampling dates been available in early 1998 when the species list for inclusion in this EDYS application was made.

Two composite species were used to simulate shrubs and succulents. Snakeweed was used as the composite for all semi-shrubs and creosotebush was used as the composite for all woody shrubs and all succulents (Table 14). A separate

composite for succulents would have been used had there been more succulents in the February 1998 sampling. Five composite species simulate the grasses. Purple threeawn was used as the composite for early-seral species. Black grama was used only for black grama. Blue grama was used for all mid- and late-seral sod-forming grasses. Sand muhly was used as the composite for all species of *Muhlenbergia*. Sand dropseed was used as the composite for all caespitose grasses. Croton was used as the composite for all forbs.

Table 14. The eight composite plant species used in the EDYS simulations of the black grama grassland at Fort Bliss.

Composite Species	Included Species
Gutierrezia sarothrae (GUSH)	*Ceratoides lanata, Gutierrezia sarothrae, Yucca elata*
Larrea tridentate (LATR)	*Condalia ericoides, Flourensia cernua, Koberlinia spinosa, Larrea tridentata, Opuntia imbricata, Opuntia macrocentra, Opuntia poly-acantha, Prosopis glandulosa*
Aristida purpurea (ARPU)	*Aristida adscensionis, Aristida barbata, Aristida purpurea, En-neapogon desvauxii, Erioneuron pulchellum, Scleropogon brevi-folius*
Bouteloua eriopoda (BOER)	*Bouteloua eriopoda*
Bouteloua gracilis (BOGR)	*Bouteloua gracilis, Hilaria mutica*
Muhlenbergia arenicola (MUAR)	*Muhlenbergia arenacea, Muhlenbergia arenicola, Muhlenbergia porteri*
Sporobolus cryptandrus (SPCR)	*Panicum halli, Setaria leucopila, Sporobolus airoides, Sporobolus contractus, Sporobolus crpytandrus*
Croton pottsii (CRPO)	All annual and all perennial forbs

EDYS uses a large number of ecophysiologial variables. Each variable must be parameterized for each composite species. Examples include growth allocation (i.e., how much of the monthly primary production is allocated to each plant part), water use efficiency, tissue nitrogen concentration, initial root architecture, monthly phenology, maximum growth rate, seasonal growth rate, shading sensitivity, seed germination rate, fire sensitivity by plant part, and preference (by plant part) by herbivores. A complete listing of these variables may be found in Childress et al. (1999b). Parameterization values for each of these variables are taken from the literature for the individual composite species when available, and for nearest ecological equivalent otherwise.

Precipitation data for these simulations were from two sources. The first source was site-specific data covering the period November 1997 through October 1999. These data were monthly totals collected by Texas Tech University at a site on Otero Mesa located approximately 5 km from the black grama study sites. These data were transformed into estimated daily precipitation values, based on correlation of the monthly values with monthly values from El Paso, Texas. These

site-specific data were used in the validation tests of the simulations. For the longer simulations, daily precipitation data sets were calculated based on long-term data from the El Paso International Airport station, adjusted for the Otero Mesa sites using the correlations with the short-term site-specific precipitation data.

The simulation soil profile used for the black grama sites (Table 15) was based on Pedons 31 and 62 from Soil Survey Staff (1975). Pedon 31 is for a black grama community 9 mi east of Las Cruces, New Mexico and Pedon 62 is for a black grama community 12 mi northeast of Las Cruces. The total nitrogen values from Pedon 31 were adjusted for depth for the upper 13 inches of the EDYS profile. Soil nitrogen values below 13 inches were based on soil nitrogen distribution patterns from 9 other desert pedons (Pedon 37, sagebrush, Utah; Pedon 39, saltbush, Texas; Pedon 56, blue grama, Arizona; Pedon 57, creosotebush, Arizona; Pedon 58, sacaton, Arizona; Pedon 59, blue and black grama, Arizona; Pedon 65, mesquite, Nevada; Pedon 128, brome, California; and Pedon 130, bluebunch wheatgrass, Utah). The initial available nitrogen pool was estimated to equal 0.6% of total soil nitrogen. This was a mean value taken from three literature values: (1) 0.23%, which was the mean of 17 forest soils (Vitousek et al. 1982); (2) 0.55%, the value for the 0 to 20 cm depth of a sagebrush community (Ehrlich 1994:34), and (3) 0.94%, the mean for the 0 to 20 cm depth in two disturbed soils (Ehrlich 1994:34).

Table 15. Soil profile characteristics and parameterization values used for the black grama community, Fort Bliss.

Horizons:	A11		A12	B21	B22	C1ca			C2ca			C3	C4
Depth (in)	00-01	01-02	02-04	04-06	06-08	08-13	13-18	18-24	24-30	30-36	36-42	42-51	51-96
Moisture (%)	7	8	10	11	11	11	11	11	10	10	10	10	10
Moisture (g)	1778	2032	5080	5588	5588	13970	13970	16764	15240	15240	15240	22860	114300
Moisture (mm)	1.78	2.03	5.08	5.59	5.59	13.97	13.97	16.76	15.24	15.24	15.24	22.86	114.30
Total N (%)	0.038	0.038	0.039	0.040	0.041	0.042	0.048	0.035	0.028	0.019	0.010	0.015	0.015
Total N (g)	14.76	15.51	26.74	27.43	30.83	72.01	82.30	72.01	57.60	39.10	20.57	42.30	211.51
Avail N (ppm)	2	2	2	2	2	3	3	2	2	1	1	1	1
Avail N (mg)	89	81	160	165	185	432	494	532	346	235	123	254	1269
Organic C (%)	0.18	0.34	0.30	0.30	0.30	0.29	0.28	0.23	0.20	0.19	0.15	0.11	0.04
Organic C (g)	70.7	121.0	178.8	178.8	178.8	497.2	480.1	473.2	411.5	381.0	308.6	357.1	649.2
Bulk density (g/cc)	1.53	1.40	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.42	1.42
Sand (%)	77	71	68	68	68	67	67	67	67	67	67	72	72
Silt (%)	16	21	22	21	21	22	22	22	23	23	23	18	18
Clay (%)	7	8	10	11	11	11	11	11	11	10	10	10	10

Note: All weights are on a m^2 basis for the depth of the respective layer.

The Fort Bliss Otero Mesa experimental design consisted of a total of 24 100-m^2 (10 m x 10 m) plots at each of the two sites. Each plot received a water-nitrogen treatment combination (2 levels of water x 3 levels of nitrogen = 6 combinations) and there were 4 replications (6 treatment combinations x 4 replications = 24 plots). The 6 plots within a replication provided a test for the ability of EDYS to predict the responses of this community to variations in water and nitrogen availability. The 4 replications within a site provided for measurement of spatial variability.

EDYS simulations were run for each of the 48 plots. For validation, accuracies were calculated for each plot and then averaged by site, by treatment, and over-all. For evaluation of ecological dynamics and management scenarios, the 48 plots were used as 48 cells to develop a spatial mosaic characteristic of the over-all Otero Mesa black grama community. In this case, the initial values for each plot that were used to begin the simulations were the means for each of the eight composite species for the respective plot, averaged over the three sampling dates. Results of each simulation were reported as averages of the 48 plots. This allowed for more accurate spatial representation of the overall community than if only the baseline values were used to initiate the simulations.

Accuracy of Simulation Results

Community-Wide Accuracy

EDYS was parameterized for the black grama community in 1998, using the February 1998 baseline vegetation data and the site-specific precipitation data (Table 3). Simulations for Feb through Oct 1998 were run in Nov and Dec 1998; those results were compared to the values for the samples collected in Oct 1998. This was the first-year validation (McLendon et al. 1999a). It resulted in a 96% accuracy for total aboveground biomass, 79% accuracy for weighted biomass by lifeform, and 71% accuracy for weighted biomass by species (Table 16). The EDYS accuracy for black grama, the site-dominant, was 82%.

Simulations were run for Oct 1999 using the same parameterization that was used in the first-year validation. No adjustments, based on the first-year valida-tion simulations, were made, except to add the site-specific precipitation data for Nov 1998 through Oct 1999. This was a blind validation test since none of the original parameterization values were changed.

The accuracies of the EDYS second-year projections were 94% for total above-ground biomass, 93% for weighted biomass by lifeform, and 83% for weighted

biomass by species (Table 16). The accuracy for black grama was 93%. Overall, EDYS projections were more accurate the second year than the first year. This was probably a reflection of temporal and spatial heterogeneity in the community. Lifeform and species composition in Oct 1999 were more similar to the composition in Feb 1998 than was the composition in Oct 1998 (Table 2). For example, perennial grass relative biomass was 96% on the 1986-burned site in Feb 1998, 88% in Oct 1998, and 93% in Oct 1999. The respective values for the 1995-burned site were 92% in Feb 1998, 83% in Oct 1998, and 87% in Oct 1999. Correspondingly, the EDYS accuracy in predicting perennial grass biomass was 85% in Oct 1998 and 94% in Oct 1999.

Spatial heterogeneity is also important, especially for shrubs, because species that have a clumped distribution pattern are more difficult to adequately sample with a fixed sampling design (McLendon 1995). One sampling exercise may result in relatively low values and another sampling, even from the same site, may result in much higher values, because of the location of randomly-located plots. No yucca occurred in the samples collected at the 1986-burned site in February 1998, but 5% of all biomass collected at the same site 8 months later was yucca. Yucca is a relatively large perennial, and it is certain that the plants did not suddenly appear at the site between February and October 1998. Instead, the random locations of the sampling quadrats missed the existing plants in February but included them in October.

The spatial heterogeneity can also be seen in the statistical variation in the values of each of the biomass variables (Figure 8). Variables that are distributed relatively evenly over a landscape will have low sample variation, and therefore tight confidence intervals. Variables with high variation, caused by a wide-range in values among the observations, will have wide confidence intervals. At the Otero Mesa site, total grass biomass is relatively uniformly distributed. With a mean of 142, it has a 95% confidence interval of ± 10. Black grama also occurs evenly across the area, but since it is a single species, even though the most abundant single species, it is not as evenly distributed as total grass biomass. Black grama (BOER) has a mean of 120 and a 95% confidence interval of ±10. Both variables have the same confidence interval, but total grass has a larger mean, therefore the variability is less proportional to the mean than it is for black grama. In contrast, the creosotebush composite species (LATR) has a confidence interval of 6, but a mean of only 10. And, creosotebush plants do in fact have a much more clumped distribution pattern than black grama or total grasses.

Table 16. One- and 2-year EDYS validation results for the black grama community at Fort Bliss.

Variable	Sampled	Predicted	Ratio	Relative Biomass	Weighted Score
First-year (Oct 98)					
Total aboveground	193.7	202.2	0.958		
Litter	28.2	27.8	0.986		
Shrubs	23.3	5.2	0.223	0.120	0.027
Grasses	165.1	195.4	0.845	0.852	0.752
Forbs	5.3	1.6	0.302	0.027	0.008
Total for Lifeform				0.999	0.787
Gutierrezia sarothrae	9.2	2.6	0.283	0.047	0.013
Larrea tridentata	14.1	2.6	0.184	0.073	0.013
Aristida purpurea	2.2	5.8	0.379	0.011	0.004
Bouteloua eripoda	140.6	171.4	0.820	0.726	0.595
Bouteloua gracilis	4.7	1.6	0.340	0.024	0.008
Muhlenbergia arenicola	11.5	9.0	0.784	0.059	0.046
Sporobolus cryptandrus	6.1	7.5	0.813	0.031	0.025
Croton pottsii	5.3	1.6	0.302	0.027	0.008
Total for species				0.998	0.712
Second-year (Oct 99)					
Total aboveground	158.1	168.9	0.936		
Litter	30.4	22.5	0.740		
Shrubs	13.2	27.5	0.480	0.083	0.040
Grasses	141.9	140.4	0.989	0.898	0.886
Forbs	3.0	1.0	0.333	0.019	0.006
Total for Lifeform				1.000	0.932
Gutierrezia sarothrae	2.9	6.2	0.468	0.018	0.008
Larrea tridentata	10.3	21.3	0.484	0.065	0.031
Aristida purpurea	2.0	15.1	0.132	0.013	0.002
Bouteloua eripoda	119.6	111.5	0.932	0.757	0.706
Bouteloua gracilis	3.7	1.4	0.378	0.023	0.009
Muhlenbergia arenicola	9.7	4.7	0.485	0.061	0.030
Sporobolus cryptandrus	6.9	7.8	0.885	0.044	0.039
Croton pottsii	3.0	1.0	0.333	0.019	0.006
Total for species				1.000	0.831

Note: Sampled and predicted values are biomass values (g/m^2) for the respective dates. Weighted score = Ratio x Relative biomass.

The accuracies (ratios) reported in Table 16 are used as measurements of the simulation accuracy of EDYS. The accuracies in the table are, in fact, simulation accuracies plus sampling accuracies. They reflect the differences between the sampled values and the predicted values, but they also contain variation resulting from sampling. The differences between the sampled values in February

1998 and October 1999 also contain sampling error, and this sampling "noise" in the data should be accounted for to separate it from modeling error. Otherwise, all variability (i.e., predictive error or "noise") is attributed to the model simulations.

One method of accounting for sampling variability is to use confidence intervals of the population means for each composite species (Snedecor and Cochran 1989, Bonham 1989, McLendon 1995). These intervals give the statistical ranges for the means of each variable that are the best statistical estimates of the true value of that mean. As such, they are a measurement of the sample accuracy for that variable.

The EDYS simulation values were within these 95% confidence intervals for all 13 of these variables (Figure 8), indicating that the EDYS projections were as accurate as the sampling.

Paired t-tests (Snedecor and Cochran 1989, McLendon 1995) were also used to test the significance of the differences between the sampled values and the respective EDYS predicted values for each of the 12 simulation values from the 48 plots. (*Croton pottsii* is the same as total forbs.) This is a very rigorous test for simulations because it compares the sampled and predicted values plot-by-plot. In effect, the 48 plots become 48 validation replications.

The results of the paired-t tests were similar to those from the confidence intervals (Table 17). Five of the 12 simulated means were not significantly different from the corresponding sampled means. These were: total aboveground biomass, total grass biomass, snakeweed biomass, black grama biomass, and sand dropseed biomass. Of these five, the three species whose simulated values were not significantly different from the sampled values comprised 82% of the sampled relative biomass of the grassland. This value is very close to the 83% weighted score method of evaluating the accuracy of EDYS in predicting individual species biomass (Table 16).
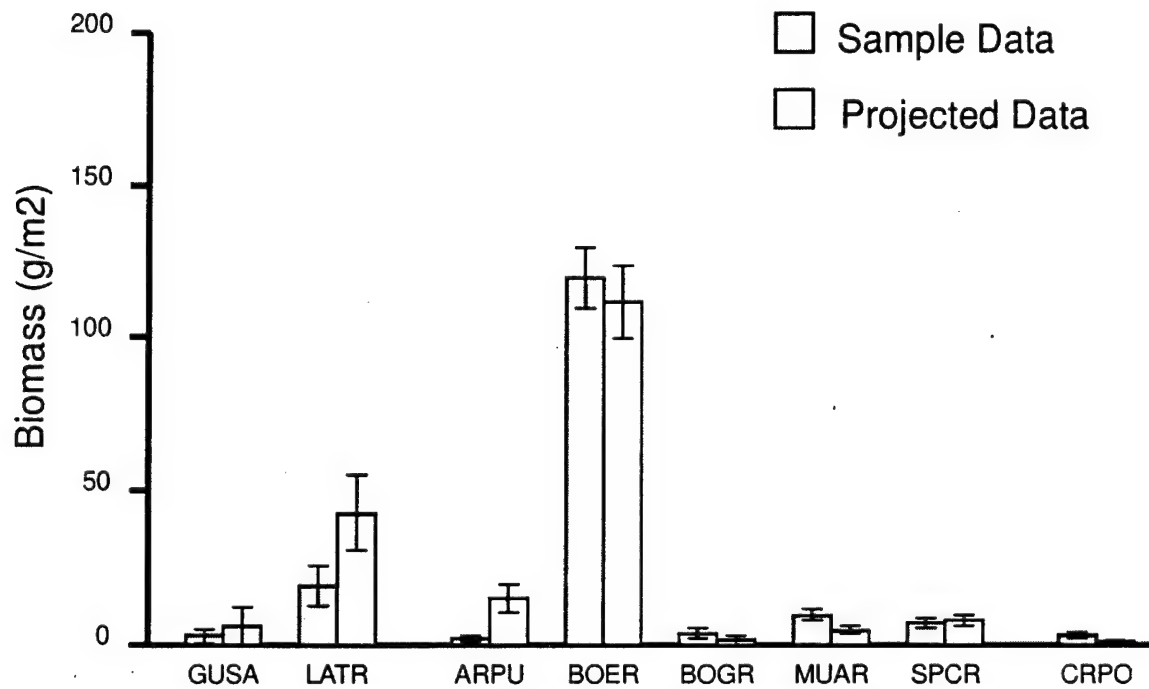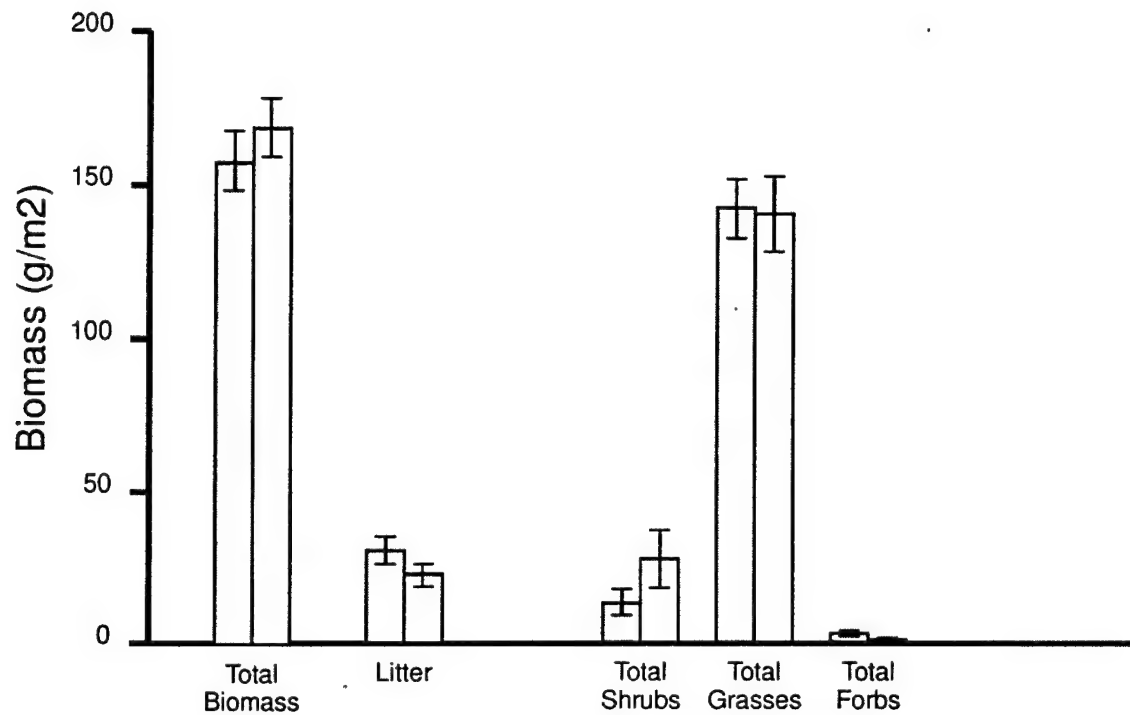
Figure 8. Comparison of sampled and EDYS projections of aboveground biomass, second-year validation (Oct 1999), black grama grassland, Fort Bliss.

Table 17. Results of paired t-test comparisons of EDYS predicted values to the respective sampled values for 13 simulation biomass variables, black grama grassland, Fort Bliss, October 1998.

Variable	Calculated t	Significant t	
		P = 0.05	P = 0.01
Total aboveground	1.97	2.01	2.69
Litter	3.39	2.01	2.69
Total shrub	3.07	2.01	2.69
Total grass	0.27	2.01	2.69
Gutierrezia sarothrae	1.10	2.01	2.69
Larrea tridentata	3.11	2.01	2.69
Aristida purpurea	6.83	2.01	2.69
Bouteloua eriopoda	1.47	2.01	2.69
Bouteloua gracilis	3.06	2.01	2.69
Muhlenbergia arenicola	5.46	2.01	2.69
Sporobolus cryptandrus	0.65	2.01	2.69
Croton pottsii	4.60	2.01	2.69

Note: There were 48 observations (plots) for each variable.

Water and Nitrogen Effects

One of the primary purposes of this research was to determine how accurately EDYS could simulate changes in plant community dynamics caused by changes in water and nitrogen availability. To test this, the simulation results were separated by treatments and sites and compared to their respective sampled values.

EDYS was very sensitive to the effect of water supply on plant community dynamics. The water treatment increased the annual water supply by only 8% and EDYS accurately simulated these effects (Table 18). The accuracy ratios for total aboveground biomass were equal for the added water and precipitation-only treatments, 0.93 and 0.94, respectively. The water treatment resulted in a 3.0 g increase in sampled total aboveground biomass. The EDYS simulation had a 4.2-g increase. Accuracies were also similar for most species and lifeforms. The water treatment decreased sampled biomass of black grama and blue grama and the EDYS simulation values were also lower on the water treatment plots. The water treatment increased shrub biomass approximately 50%, compared to the control, and the EDYS simulated values were also approximately 50% higher on the water plots. The sampled value of sand dropseed was 0.2 g higher on the plots receiving added water; the EDYS simulation value also increased by 0.2 g.

EDYS did not accurately predict the response patterns of purple threeawn and sand muhly to water. Both species increased with increased water but the EDYS simulations indicated that purple threeawn would decrease and sand muhly biomass would remain constant.

The EDYS simulations were slightly less sensitive to changes in nitrogen availability (Table 19) than they were to the water treatment. The accuracies for predicting total aboveground biomass were 0.996 for the high nitrogen treatment, 0.90 for moderate nitrogen, and 0.95 for low nitrogen. The species weighted average accuracies were 0.81, 0.87, 0.78 for high, moderate, and low nitrogen, respectively. EDYS simulated the response of grasses to nitrogen availability very well, with accuracies of 0.98, 0.99, and 0.998 for the three levels. The accuracies for black grama were only slightly lower, 0.92, 0.99, and 0.88.

Table 18. EDYS validation results for the water treatment in the black grama grassland at Fort Bliss.

Variable	Sampled	Predicted	Ratio	Relative Biomass	Weighted Score
Added water					
Total aboveground	159.6	171.0	0.933		
Litter	30.4	23.5	0.773		
Total shrubs	15.4	32.8	0.470	0.096	0.045
Total grasses	141.2	137.5	0.974	0.885	0.862
Gutierrezia sarothrae	3.3	8.8	0.375	0.027	0.010
Larrea tridentata	12.1	24.0	0.504	0.076	0.038
Aristida purpurea	2.2	13.5	0.163	0.014	0.002
Bouteloua eriopoda	118.8	111.0	0.934	0.738	0.689
Bouteloua gracilis	2.5	0.4	0.160	0.016	0.003
Muhlengergia arenicola	10.6	4.7	0.443	0.066	0.029
Sporobolus cryptandrus	7.1	7.9	0.899	0.044	0.040
Croton pottsii	3.0	1.0	0.333	0.019	0.063
Total for species					0.874
Precipitation only					
Total aboveground	156.6	166.8	0.939		
Litter	30.2	21.6	0.715		
Total shrubs	10.9	22.1	0.494	0.070	0.035
Total grasses	143.0	143.5	0.996	0.913	0.909
Gutierrezia sarothrae	2.4	3.5	0.686	0.015	0.010
Larrea tridentata	8.5	18.6	0.457	0.054	0.025
Aristida purpurea	1.9	16.7	0.114	0.012	0.001
Bouteloua eriopoda	120.4	112.0	0.930	0.769	0.715
Bouteloua gracilis	4.9	2.3	0.469	0.031	0.015
Muhlengergia arenicola	8.9	4.8	0.539	0.057	0.031
Sporobolus cryptandrus	6.9	7.7	0.896	0.044	0.039
Croton pottsii	2.7	1.1	0.407	0.017	0.007
Total for species					0.843

Note: Sampled and predicted values are biomass values (g/m^2) for October 1999. Weighted score = Ratio x Relative biomass.

Table 19. EDYS validation results for the nitrogen availability treatment in the black grama grassland at Fort Bliss.

Variable	Sampled	Predicted	Ratio	Relative Biomass	Weighted Score
High N					
Total aboveground	162.8	163.4	0.996		
Litter	28.8	18.7	0.649		
Shrubs	13.4	19.8	0.677	0.082	0.056
Grasses	145.1	142.5	0.982	0.891	0.875
Gutierrezia sarothrae	2.1	1.6	0.762	0.013	0.010
Larrea tridentata	11.3	18.3	0.617	0.069	0.043
Aristida purpurea	4.4	18.8	0.234	0.027	0.006
Bouteloua eriopoda	117.9	108.8	0.924	0.724	0.669
Bouteloua gracilis	4.2	1.7	0.405	0.026	0.011
Muhlengergia arenicola	11.5	4.4	0.383	0.071	0.027
Sporobolus cryptandrus	7.1	8.8	0.807	0.043	0.035
Croton pottsii	4.3	1.1	0.256	0.026	0.007
Total for Species					0.808
Moderate N					
Total aboveground	165.6	183.8	0.901		
Litter	32.5	24.6	0.757		
Shrubs	12.1	33.3	0.363	0.073	0.027
Grasses	151.8	149.9	0.987	0.917	0.905
Gutierrezia sarothrae	4.4	13.5	0.326	0.027	0.009
Larrea tridentata	7.7	19.8	0.389	0.047	0.019
Aristida purpurea	0.8	11.0	0.073	0.005	0.000
Bouteloua eriopoda	130.2	128.6	0.988	0.786	0.777
Bouteloua gracilis	2.4	0.1	0.042	0.015	0.001
Muhlengergia arenicola	9.8	5.1	0.520	0.059	0.031
Sporobolus cryptandrus	8.6	5.1	0.593	0.052	0.031
Croton pottsii	1.7	0.6	0.353	0.010	0.004
Total for Species					0.872
Low N					
Total aboveground	145.6	159.4	0.945		
Litter	30.1	22.8	0.757		
Shrubs	13.9	29.3	0.474	0.096	0.046
Grasses	129.1	128.8	0.998	0.887	0.885
Gutierrezia sarothrae	2.0	3.4	0.588	0.014	0.008
Larrea tridentata	11.9	25.9	0.459	0.082	0.038
Aristida purpurea	0.8	15.6	0.051	0.006	0.000
Bouteloua eriopoda	110.8	97.1	0.876	0.756	0.662
Bouteloua gracilis	4.5	2.2	0.489	0.031	0.015
Muhlengergia arenicola	7.8	4.5	0.577	0.054	0.031
Sporobolus cryptandrus	5.2	9.4	0.553	0.036	0.020
Croton pottsii	2.6	1.3	0.500	0.018	0.009
Total for Species					0.783

Note: Sampled and predicted values are biomass values (g/m^2) for October 1999. Weighted score = Ratio x Relative biomass.

The simulation accuracies were about equal between the two sites for total aboveground biomass (0.93 and 0.94, Table 20). However, there were greater differences between sites for most variables than were common for either water or nitrogen treatments. This was largely because of the greater amount of shrubs on the 1995 burned site than on the 1986 burned site.

Table 20. EDYS validation results for the site differences in the black grama grassland at Fort Bliss.

Variable	Sampled	Predicted	Ratio	Relative Biomass	Weighted Score
Burned 1986					
Total aboveground	162.4	174.5	0.931		
Litter	23.6	19.4	0.822		
Shrubs	7.0	10.7	0.654	0.043	0.028
Grasses	151.4	162.7	0.931	0.932	0.868
Gutierrezia sarothrae	5.4	10.7	0.504	0.033	0.017
Larrea tridentata	1.6	0.0	0.000	0.010	0.000
Aristida purpurea	0.7	15.2	0.046	0.004	0.000
Bouteloua eriopoda	133.1	132.0	0.992	0.820	0.813
Bouteloua gracilis	1.1	0.1	0.091	0.007	0.001
Muhlengergia arenicola	9.5	4.5	0.474	0.059	0.028
Sporobolus cryptandrus	7.0	10.9	0.642	0.043	0.028
Croton pottsii	4.0	1.1	0.275	0.025	0.007
Total for Species					0.894
Burned 1995					
Total aboveground	153.7	163.2	0.942		
Litter	37.2	25.8	0.694		
Shrubs	19.3	44.2	0.437	0.126	0.055
Grasses	132.6	118.1	0.891	0.863	0.769
Gutierrezia sarothrae	0.4	1.6	0.250	0.003	0.001
Larrea tridentata	18.9	42.6	0.444	0.123	0.055
Aristida purpurea	3.4	15.0	0.227	0.022	0.005
Bouteloua eriopoda	106.1	91.0	0.858	0.690	0.592
Bouteloua gracilis	6.3	2.6	0.413	0.041	0.017
Muhlengergia arenicola	9.9	4.9	0.495	0.064	0.032
Sporobolus cryptandrus	6.9	4.6	0.667	0.045	0.030
Croton pottsii	1.7	0.9	0.529	0.011	0.006
Total for Species					0.738

Note: Sampled and predicted values are biomass values (g/m^2) for October 1999.

Plant Community Responses to Fire, Cattle Grazing, and Drought

The EDYS model parameterized for the experimental plots in the black grama grassland at Fort Bliss was used to simulate 40-year plant community responses to stresses from natural fires, cattle grazing, and drought. Results of these simulations are discussed in the following paragraphs.

Effects of Fire

Without fire, the EDYS simulations indicated that snakeweed aboveground biomass will almost quadruple in 40 years (Table 21). Both fire frequencies reduced this increase in snakeweed biomass. After 40 years, snakeweed aboveground biomass was 50% less with a 5-year fire frequency, and 16% less with a 15-year fire frequency, than with no fire.

Table 21. EDYS simulation of effects of fire on total aboveground biomass (g/m^2) of an ungrazed black grama grassland, Otero Mesa, Fort Bliss, over 40 years under an average precipitation pattern.

	Unburned				5-Year Burns				15-Year Burns			
	10	20	30	40	10	20	30	40	10	20	30	40
Creosotebush	7	7	6	6	8	7	6	6	7	7	6	6
Snakeweed	14	34	46	54	13	27	33	27	14	30	37	45
Purple threeawn	16	24	33	44	15	23	30	37	16	24	30	42
Black grama	254	255	303	506	234	227	259	350	254	245	277	500
Blue grama	1	0	t	0	1	0	t	0	1	0	t	0
Sand muhly	3	1	1	1	3	1	t	1	3	1	t	1
Sand dropseed	6	4	1	1	6	3	1	1	6	3	1	1
Forbs	3	3	4	4	2	2	2	1	3	3	3	3
Total aboveground	304	328	394	616	282	290	331	423	304	313	354	598

Fire also reduced the aboveground biomass of the perennial grasses, especially black grama. Without fire and livestock grazing, black grama aboveground biomass doubled in 40 years. This was the result of both lack of cattle grazing and a 50% increase in average precipitation (Table 22). Precipitation data from El Paso indicates a remarkable 50% increase in 10-year precipitation averages over the past 40 years. Assuming a similar trend has occurred at the Otero Mesa site, this should have a major effect on the productivity of the black grama community. The EDYS simulations reflect this in the doubling of black grama aboveground biomass.

Table 22. Annual precipitation pattern (inches) used in the EDYS simulations for Otero Mesa, Fort Bliss.

	Year	Precipitation	Year	Precipitation	Year	Precipitation	Year	Precipitation
	01	9.06	11	27.33	21	19.11	31	19.99
	02	13.93	12	7.93	22	6.90	32	9.29
	03	10.73	13	14.50	23	9.64	33	11.62
	04	10.29	14	12.23	24	11.51	34	20.08
	05	12.67	15	13.17	25	14.31	35	17.44
	06	7.03	16	7.83	26	11.97	36	12.70
	07	10.16	17	8.51	27	22.18	37	25.71
	08	10.65	18	8.60	28	9.87	38	12.97
	09	8.65	19	14.69	29	16.12	39	19.35
	10	17.81	20	9.09	30	8.75	40	17.39
Mean		11.10		12.34		13.04		16.65
Total		110.98		123.88		130.36		166.54
40-year Mean = 13.29								

The 5-year fire frequency reduced black grama aboveground biomass by 30% and threeawn aboveground biomass by almost 20% after 40 years (Table 21). However, the 15-year fire frequency had only a minor effect on aboveground biomass of both black grama and threeawn. These results indicate that the 5-year fire frequency is too frequent for this ecosystem. An optimum frequency is probably close to 15 years. This modeling conclusion is supported by the field sampling data from the two sites. The site last burned in 1995 (4 years prior to the 1999 sampling) had 20% less stems and leaves of black grama than the site last burned in 1986 (13 years prior to the 1999 sampling) (Table 20).

It should be noted that the values in Table 21 are total aboveground biomass values and not leaves and stems only. Leaves and stems are normally sampled for forage production, and the stem and leaf total was harvested for the validation portion of the study and was modeled for the validation (e.g., Table 17). Total aboveground biomass is a more valuable ecological parameter since much of the perennial tissue is in the trunk (crowns in grasses) component.

Effects of Cattle Grazing

At a stocking rate of 60 acres per animal unit (Ac/AU), cattle grazing decreased aboveground biomass of perennial grasses and increased aboveground biomass of shrubs (Table 23). The effects of grazing at this stocking rate were relatively minor for the first 10 years. Production of black grama showed a strong decrease, compared to no grazing, during the second 10 years, but there was little change in threeawn or shrub production. By Year 30, the impact of grazing was reflected in threeawn production, and by Year 40, shrubs were increasing over the ungrazed scenario.

Table 23. EDYS simulation of effects of cattle grazing on aboveground biomass (g/m^2) of a black grama grassland, Otero Mesa, Fort Bliss.

	Ungrazed				60 Ac/AU				45 Ac/AU			
	10	20	30	40	10	20	30	40	10	20	30	40
Creosotebush	7	7	6	6	6	7	7	7	4	5	5	5
Snakeweed	14	34	46	54	11	36	51	67	8	26	13	6
Purple threeawn	16	24	33	44	12	24	16	27	7	5	2	9
Black grama	254	255	303	506	205	139	111	187	162	67	50	111
Blue grama	1	0	t	0	2	t	t	t	2	t	t	t
Sand muhly	3	1	1	1	3	2	1	2	4	2	2	4
Sand dropseed	6	4	1	1	5	3	1	2	4	4	2	1
Forbs	3	3	4	4	2	3	3	2	1	t	t	t
Total aboveground	304	328	394	616	246	214	190	294	192	107	73	138

Note: The simulation was for 40 years, under an average precipitation pattern and with no fire.

These results indicate that a sustained year-long stocking rate of 60 Ac/AU is too heavy for this plant community, even during a period of increased annual precipitation. Stocking at this rate could be tolerated for relatively short periods of time (e.g., less than 10 years), but grazing for 10 years or more at this rate will result in decreased productivity of the grassland and a shift toward a shrub-dominated plant community. We did not investigate lighter stocking rates in this report to determine what stocking rate could be sustained over a long period of time, but this is one of the ways that EDYS can be used to develop sustainable management systems.

Detrimental impacts to this system are increased as stocking rate increases (45 Ac/AU, Table 23). A 25% increase in stocking rate decreased black grama aboveground biomass by 40%. The decrease in shrub biomass at the heavier stocking rate at first seems surprising. However, this is the result of increased herbivory by jackrabbits. As production of preferred forage species decreases, jackrabbit herbivory of shrubs increased, especially during winter months and during dry periods. In a more realistic landscape application of the model, some of the jackrabbits would probably migrate to areas with more forage. Consequently, the shrubs would increase even more at the 45 Ac/AU stocking rate than at the 60 Ac/AU rate.

Cattle Diets

Stocking rate had little effect on cattle diets (Table 24). At stocking rates of both 45 Ac/AU and 30 Ac/AU, cattle mostly consumed black grama. This is a highly preferred forage species for cattle and there were sufficient amounts of black grama present in most months to satisfy the demand. Because black grama is so

abundant in this plant community (70 to 85% relative biomass), it constitutes the primary forage species.

Table 24. EDYS simulation of effects of stocking rate on diets of cattle grazing a black grama grassland, Otero Mesa, Fort Bliss.

Plant	45 Ac/AU				30 Ac/AU			
	10	20	30	40	10	20	30	40
Creosotebush	3	0	0	0	0	0	0	0
Snakeweed	1	0	t	0	t	0	t	0
Purple threeawn	6	6	8	5	7	7	8	6
Black grama	87	92	90	94	87	90	90	93
Blue grama	t	t	t	t	4	t	t	t
Sand muhly	t	t	1	0	t	1	1	t
Sand dropseed	2	2	1	t	2	2	1	1
Forbs	t	0	0	0	0	0	0	0

Note: Values are percent of annual diet. Simulations are for 40 years, under an average precipitation pattern with no fire. The two stocking rates were 45 Ac/AU and 30 Ac/AU.

Purple threeawn was the second most important forage species, comprising 5 to 8% of cattle diets when stocked at 45 Ac/AU and slightly more at 30 Ac/AU (Table 24). Small amounts (1 to 4% of overall diet) of blue grama, sand dropseed, and sand muhly were consumed. However, cattle occasionally consumed significant amounts of these species during certain months. For example, sand dropseed comprised about 10% of cattle diets in November for the first 20 years of the simulation.

The 40-year EDYS simulations suggest that the primary effects of stocking rate on this black grama rangeland, under the increasing precipitation pattern that the area has experienced during the past 40 years (Table 22), are to decrease the productivity of black grama and to increase the composition of shrubs. Although the plant community can provide sufficient forage to maintain heavy cattle grazing for at least 40 years, the cumulative effect of heavy grazing will result in range degradation. Over longer periods of time, this will result in shifts in cattle diets and decreased livestock production, in addition to destruction of the black grama community.

During the past 40 years, average annual precipitation (10-year averages) has increased a remarkable 50% (Table 22). This must have had a significant impact on vegetation dynamics. This increase in precipitation is probably the reason the simulated black grama community was able to support heavy grazing for 40 years with less than expected detrimental effects. If precipitation had not in-

creased so much, the plant community would probably have shifted to a shrub-land much sooner.

Effects of Precipitation Shifts

The overall effect of a simulated 10% decrease in precipitation over 10 years was to reduce aboveground biomass of most species (Table 25). Total aboveground biomass was reduced by 23%, compared to the normal precipitation pattern (Table 23). Black grama was reduced 24%, threeawn 25%, and shrubs 24%.

Table 25. EDYS simulation of drought effects on aboveground biomass (g/m^2) of a black grama grassland, without fire, Otero Mesa, Fort Bliss.

	Ungrazed				Grazed 45 Ac/AU			
	10	20	30	40	10	20	30	40
Creosotebush	6	6	6	6	4	4	4	5
Snakeweed	10	32	47	59	5	14	3	1
Purple threeawn	12	23	30	37	6	5	t	8
Black grama	194	155	151	230	156	73	49	85
Blue grama	2	t	t	t	2	1	t	t
Sand muhly	3	1	1	2	4	3	2	4
Sand dropseed	5	2	t	1	4	2	t	2
Forbs	2	3	3	4	1	t	t	t
Total aboveground	234	222	238	339	182	102	58	105

Note: The simulation was for 40 years. Drought was modeled as a 10% decrease in the normal precipitation pattern.

The effect of reduced precipitation was more severe over time. After 40 years, total aboveground biomass was 45% below normal (compare to Table 23). Equally important ecologically, this reduction was primary the result of a reduction in black grama (55%). Threeawn was reduced by only 16%, creosotebush and forbs were not reduced, and snakeweed increased by 9%.

These results indicate that the longer drought occurs, the more significant its impact on the black grama community. For 20 years, the effect is reduced productivity only. Species composition remains stable. After 20 years, both productivity and composition are impacted. Black grama begins to decrease in abundance and shrubs increase. This relationship between drought and the decrease in black grama and increase in shrubs has been documented on nearby black grama communities (Nielson 1987, Gibbens and Beck 1988).

The effect of drought was very similar to the effect of cattle grazing at a stocking rate of 60 Ac/AU. When combined with drought, cattle grazing intensified the effect of drought. Grazing at 45 Ac/AU decreased total aboveground biomass 40%

after 10 years of drought, compared to a 23% decrease from drought alone, and decreased black grama 39%, compared to 24% from drought only. After 40 years of reduced precipitation, grazing reduced total aboveground biomass and black grama by 83%. Therefore, the combination of grazing and drought is particularly destructive to this plant community. This also has been reported from field research (Gibbens and Beck 1988).

Increased precipitation increases the relative abundance of perennial grasses, especially black grama. A 10% increase in precipitation, continued over 40 years, results in a 25% increase in total aboveground biomass, compared to the normal precipitation pattern (Table 26). Black grama increases by 28% and threeawn increases by 14%. Shrubs also increase, but at a slower rate (12%) than the grasses. Therefore, the community becomes even more of a grassland. This pattern is also suggested by our results of the water treatment, where an 8% increase in water over a 1-year period resulted in a decrease in relative biomass of shrubs and a slight increase in relative biomass of perennial grasses.

Table 26. EDYS simulation of effects of increased precipitation on aboveground biomass (g/m^2) of a black grama grassland, Otero Mesa, Fort Bliss.

	Ungrazed				Grazed 45 Ac/AU			
	10	20	30	40	10	20	30	40
Creosotebush	9	9	8	8	6	8	8	9
Snakeweed	17	44	51	59	13	38	54	72
Purple threeawn	19	27	37	50	14	27	28	37
Black grama	246	325	401	646	223	167	151	292
Blue grama	1	0	t	0	2	t	t	t
Sand muhly	3	1	1	1	4	2	1	2
Sand dropseed	7	6	4	3	6	5	1	3
Forbs	4	4	4	5	3	3	4	4
Total aboveground	306	416	506	772	271	250	247	419

Note: The simulation was for 40 years, without fire. Daily precipitation values were increased by 10% in this simulation.

Cattle grazing, at a stocking rate of 45 Ac/AU, had a significant effect on the community dynamics under increased precipitation. After 40 years, perennial grass aboveground biomass was about half of that without grazing and shrub biomass was 35% higher (Table 26). These results suggest that during periods of increased precipitation, relatively heavy grazing can be sustained by the community, but at the cost of increased abundance of shrubs.

Little Bluestem Grassland, Fort Hood

Selection of Species and Parameterization of EDYS

Eight composite species were included in the simulations of the little bluestem grassland: little bluestem (*Schizachyrium scoparium*), silver bluestem (*Bothriochloa saccharoides*), hairy grama (*Bouteloua hirsuta*), seep muhly (*Muhlenbergia reverchonii*), Texas wintergrass (*Stipa Leucotricha*), broomweed (*Amphiachyris drancunculoides*), littletooth sedge (*Carex microdonta*), and frogfruit (*Phyla nodiflora*). These were the most abundant species encountered in the March 1998 sampling, comprising 64% of the aboveground biomass at that date. Twenty-five other species contributed the remaining 36% of the biomass. When averaged over the three sampling dates, the 8 most abundant composite species accounted for 73% of aboveground biomass and 48 other species accounted for the remaining 27%.

Two species, tall dropseed and sumpweed, had relative biomass values greater than 5% over the three sampling dates, and would have been included in the model had data from the three sampling dates been available in early 1998 when the species list for inclusion in this EDYS application was made. However, neither species was identified in the March 1998 baseline sampling. Therefore, they were not included in this application of the EDYS model to the Fort Hood site.

We used five composite species to simulate grasses and three composite species to simulate forbs (Table 27). Little bluestem was used as the composite for late-seral mid- and tall-grasses. Silver bluestem was used as the composite for mid-seral mid-grasses. Texas wintergrass was used to represent cool-season grasses. Seep muhly was used as the composite for grasses characteristic of relatively wet sites. Hairy grama was used as the composite for short-grasses and sod-forming grasses. Broomweed was used as the composite for annual forbs, littletooth sedge for geophytes and hemicryptophytes (Daubenmire 1968:64), and frogfruit for all other perennial forbs.

Precipitation data for the Fort Hood simulations were daily precipitation values from Gray Army Air Field (AAF), located 5 km NW of the study site. The simulated soil profile (Table 28) was based on Cisco sandy loam (McCaleb 1985) and Pedon 4 (Soil Survey Staff 1975).

Table 27. List of the eight composite plant species used in the EDYS simulations of the little bluestem grassland at Fort Hood.

Composite Species	Included Species
Bothriochloa saccharoides (Bosa)	Bothriochloa saccharoides, Bouteloua curtipendula, Panicum hallii, Panicum obtusum, Scorobolus asper
Bouteloua hirsuta (Bohi)	Aristida purpurea, Bothriochloa ischaemum, Bouteloua gracilis, Bouteloua hirsuta, Bouteloua rigidiseta, Buchloe dactyloides.
Muhlenbergia reverchonii (Mure)	Eragrostis elliotii, Muhlenbergia reverchonii
Schizachyrium scoparium (Scsc)	Schizachyrium scoparium, Sorghastrum nutans
Stipa leucotricha (Stle)	Agrostis hiemalis, Dicanthelium oligosanthes, Stipa leucotricha
Amphiachyris drancunculoides (Amdr)	All annual forbs
Carex microdonta (Cami)	Allium sp., Carex microdonta, Eleocharis acutisquamata, Sisyrinchium sp.
Phyla nodiflora (Phno)	All other perennial forbs

Table 28. Available water holding capacity, available nitrogen, and carbon for the little bluestem grassland, Fort Hood.

Horizon	A		Bt1			Bt2		Bk1		Bk2	C		
Depth (inches)	00-01	01-04	04-10	10-16	16-23	23-32	32-41	41-50	50-58	58-68	68-80	80-92	92-120
Moisture (%)	11	12	13	14	15	14	13	12	12	11	10	10	10
Moisture (g/m^2)	2794	9144	19812	21336	26670	32004	29718	27432	24384	27940	30480	30480	71120
Moisture (mm)	2.79	9.14	19.81	21.34	26.67	32.00	29.72	27.43	24.38	27.94	30.48	30.48	71.12
Avail N (ppm)	171	155	133	110	87	69	55	44	35	28	23	18	15
Avail N 9mg)	6732	17717	29886	24364	22147	23029	18608	15088	10748	11024	10973	8778	16500
Total N (%)	0.342	0.310	0.265	0.219	0.173	0.138	0.110	0.088	0.070	0.056	0.045	0.036	0.029
Total N (g)	134.6	354.3	597.7	487.3	442.9	460.6	372.2	301.8	215.0	220.5	219.5	175.6	330.0
Organic C (%)	4.35	4.00	3.61	2.30	2.10	1.90	1.70	1.50	1.30	1.00	0.70	0.40	0.10
Organic C (g)	1713	4572	8142	5118	5377	6341	5752	5144	3962	3937	3414	1951	11379
Bk density (g/cc)	1.55	1.50	1.48	1.46	1.44	1.46	1.48	1.50	1.50	1.55	1.60	1.60	1.60
Sand (%)													
Silt (%)													
Clay (%)	13	16	20	23	26	28	30	30	25	20	15	10	5

Note: Data are estimates based on the Cisco sandy loam (McCaleb 1985) and Pedon 4, Soil Survey Staff (1978). Moisture values are available soil moisture. Available N was estimated to be 0.05% of total N.

The Fort Hood experimental design consisted of 24 100-m^2 plots. Each plot received a water-nitrogen treatment combination (2 levels of water x 3 levels of nitrogen = 6 combinations) and there were 4 replications (6 treatment combinations x 4 replications = 24 plots). The 6 plots within a replication provided a test for the ability of EDYS to predict the responses of this community to variations in water and nitrogen availability. The 4 replications provided for measurement of spatial variability.

EDYS simulations were run for each of the 24 plots. For validation purposes, accuracies were calculated for each plot and then averaged by treatment and overall. For purposes of evaluation of ecological dynamics and management scenarios, the baseline composite species values for the 24 plots were averaged and these average values were used to initiate the simulations.

Accuracy of Simulation Results

Community-Wide Accuracy

EDYS was parameterized for the little bluestem community, using the March 1998 baseline vegetation data (Table 10) and precipitation data from Gray AAF. Simulations for March to November 1998 were run in June and July 1999 and those results were compared to the values of the samples collected in November 1998. This was the first-year validation (McLendon et al. 1999d). It resulted in 88% accuracy for total aboveground biomass, 83% for weighted biomass by lifeform, and 77% for weighted biomass by species (Table 29). The EDYS accuracy for little bluestem, the site-dominant species, was 96%.

Simulations have now been run for October 1999. Adjustments were made in seven variables. Changes in the water-use efficiency variable were made in order to incorporate additional literature data that were available for the 1999 simulations. Changes in the other six variables (green-out month, seed germination month, maximum growth rate, monthly growth rate, shading effect, accessibility of leaves to cattle) were made either on the basis of the first-year (1998) validation results or to correct errors that were discovered in the 1998 parameterization. Table 30 lists the variables with their respective values.

Table 29. One- and two-year validation results for the little bluestem community at Fort Hood.

Variable	Predicted	Sampled	Ratio	Relative Biomass	Weighted Score
First-year (Nov 98)					
Total aboveground	90.8	102.9	0.882		
Grasses	75.3	90.2	0.835	0.877	0.732
Forbs	15.6	12.7	0.814	0.123	0.100
Total for lifeform					0.832
Schizachyrium scoparium	51.4	53.3	0.964	0.518	0.499
Bothriochloa saccharoides	7.0	18.7	0.374	0.182	0.068
Bouteloua hirsuta	12.8	9.9	0.773	0.096	0.074
Muhlenbergia reverchonii	1.9	5.8	0.328	0.056	0.018
Stipa leucotricha	2.2	2.5	0.880	0.024	0.021
Amphiachyris drancunculoides	8.4	6.1	0.726	0.059	0.043
Carex microdonta	3.1	1.7	0.548	0.017	0.009
Phyla nodiflora	4.1	4.9	0.837	0.048	0.040
Total for species					0.772
Second-year (Oct 99)					
Total aboveground	209.5	207.7	0.991		
Grasses	178.0	158.2	0.889	0.762	0.677
Forbs	31.5	49.5	0.636	0.238	0.151
Total for lifeform					0.828
Schizachyrium scoparium	123.3	101.6	0.824	0.489	0.403
Bothriochloa saccharoides	20.4	38.0	0.537	0.183	0.098
Bouteloua hirsuta	25.0	7.6	0.304	0.037	0.011
Muhlenbergia reverchonii	3.3	5.5	0.600	0.026	0.016
Stipa leucotricha	6.1	5.5	0.902	0.026	0.023
Amphiachyris drancunculoides	26.3	30.8	0.854	0.148	0.126
Carex microdonta	2.4	2.5	0.960	0.012	0.012
Phyla nodiflora	2.8	16.2	0.173	0.078	0.013
Total for species					0.702

Note: Sample and predicted values are biomass values (g/m^2) for the respective dates. Ratio is the accuracy measurement and is calculated by dividing the smaller of the predicted or sampled value by the larger. The weighted score is the ratio value multiplied by the relative biomass.

Table 30. Parameter variables, with their corresponding values, that were changed in the 1999 EDYS simulations of the little bluestem community at Fort Hood.

Variable	Year	Values							
		Scsc	Bosc	Bohi	Mure	Stle	Amdr	Cami	Phno
Water-use efficiency Water-use efficiency	98 99	1.60 0.95	1.05 1.00	1.10 0.98	1.10 0.99	1.30 1.07	2.80 0.85	2.00 1.10	2.60 0.82
Green-out month Green-out month	98 99					Feb Oct			
Seed germination Seed germination	98 99					Feb-Jun Sep-Dec			
Maximum growth rate Maximum growth rate	98 99		5.00 4.00			2.00 3.00	2.50 8.00	1.00 3.00	2.00 6.00
Scsc shading effect Scsc shading effect	98 99			0.20 0.30					
Bosc shading effect Bosc shading effect	98 99			0.20 0.30				0.20 0.30	0.20 0.30
Amdr shading effect Amdr shading effect	98 99			0.00 0.15	0.00 0.05	0.00 0.05		0.00 0.05	0.00 0.05
Max leaf avail cattle Max leaf avail cattle	98 99					90 80			

Variable	Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Stle max monthly growth rate	98	0.4	0.6							0.2	0.4	0.7	0.5
Stle max monthly growth rate	99	0.5	0.8							0.4	1.0	1.0	0.8

Note: Only values that were changed are included in this table.

The accuracies of the EDYS second-year projections were 99% for total above-ground biomass, 83% for weighted biomass by lifeform, and 70% for weighted biomass by species (Table 29). The accuracy for little bluestem was 82%. EDYS projections were more accurate the second year than the first for total biomass, total grasses, and 5 of the 8 composite species. EDYS projections were less accurate for total forbs, weighted biomass by species, and 3 of the 8 composite species.

The accuracies reported in Table 29 are used as measurements of the simulation accuracy of EDYS. They are, in fact, simulation accuracies plus sampling accuracies. They reflect the differences between the sampled values and the pre-

dicted values, but they also contain variation resulting from sampling. This sampling "noise" in the data should be accounted for to separate it from modeling error. Otherwise, all variability (i.e., predictive error or "noise") is attributed to the model simulations. As with the Fort Bliss results, we used two statistical methods, confidence intervals of the population means and paired t-tests, to account for sampling variability.

The 95% confidence intervals of the population means of each of the composite variables, based on the 24 plots, were calculated for the October 1999 sampled values. These intervals give the statistical ranges for the means of each variable that are the best statistical estimates of the true value of that mean. As such, they are a measurement of the sample accuracy for that variable. These values were then compared to the 95% confidence intervals of the EDYS-predicted values for the variables. The EDYS simulation values were within the 95% confidence intervals of the sampled values for 5 of the 12 variables (Figure 9), indicating that the EDYS simulation was at least as accurate as the sampling technique for these five variables.

The seven variables for which EDYS projected values were outside the 95% confidence intervals were total grasses, total forbs, *Bothriochloa saccharoides*, *Bouteloua hirsuta*, *Schizachyrium scoparium*, *Phyla nodiflora*, and litter. In the EDYS simulation, *Bothriochloa saccharoides* was in fact a composite of five species (Table 27), two of which had much larger amounts of aboveground biomass at the October 1999 sampling date than did *Bothriochloa saccharoides* itself (Table 10). Therefore it is not surprising that the simulation for this species was weak. Likewise, Bouteloua hirsuta was a composite of six species, two of which had higher biomass values at the October 1999 sampling date than did *Bouteloua hirsuta*. The combination of the simulation means of these two composite variables (45.4 g/m^2) was very near the combined sample means (45.6 g/m^2) (Table 29), suggesting that further separation of species within this complex would probably result in more accurate simulation values.
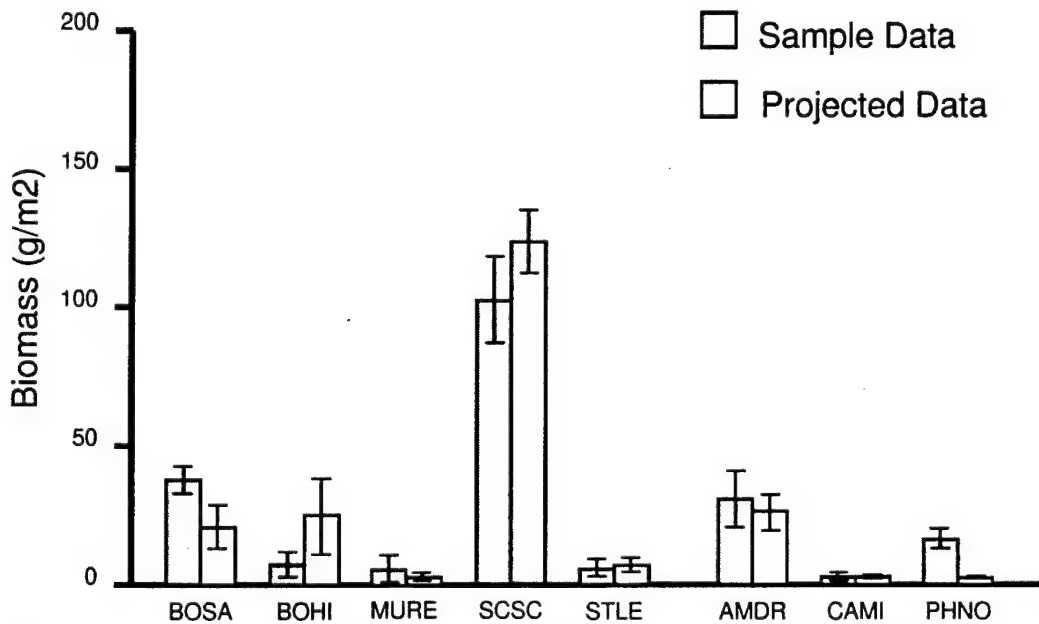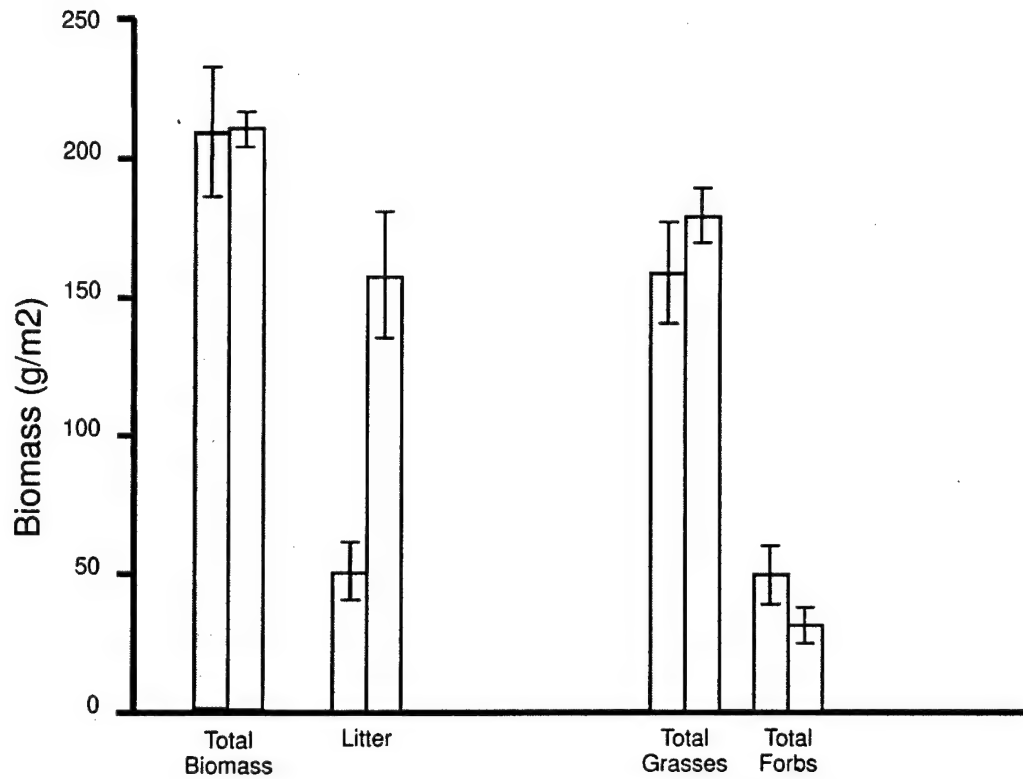
Figure 9. Comparison of sampled and EDYS projections of aboveground biomass, second-year validation (October 1999), little bluestem grassland, Fort Hood.

The simulation means for total grasses and *Schizachyrium* were very close to being included in the 95% confidence intervals of their respective sample means (Figure 9), and their confidence intervals did overlap. The simulation values for both variables were higher than the sampled values. In both cases, this was

probably because the water-use efficiency value for *Schizachyrium* was probably too low much (Table 30). This can be corrected easily in subsequent simulations.

The low accuracy for *Phyla* is probably the result of relatively weak parameterization. This is not surprising since this composite species is used in this EDYS application to simulate 26 forb species.

The results of the paired t-tests were similar to those from the confidence intervals (Table 31). Predicted values were not significantly different ($P < 0.05$) from the sampled values for 6 of the 12 variables (total aboveground biomass, total grasses, *Muhlenbergia reverchonii*, *Stipa leucotricha*, *Amphiachyris drancunculoides*, and *Carex microdonta*). Predicted values were significantly different ($P < 0.01$) from sampled values for total forbs, *Bothriochloa saccharoides*, *Phyla nodiflora*, and litter. Predicted values were significantly different from sampled values at $P < 0.05$, but not at $P < 0.01$, for *Bouteloua hirsuta* and *Schizachyrium scoparium*, and the calculated t-value for *Schizachyrium* was near the significant t-value of 2.07. For common species, the model does well. For rare species, the model is less accurate.

Table 31. Results of paired t-test comparisons of EDYS predicted values to the respective sampled values for 12 simulation variables at each of 24 plots, October 1999, Fort Hood.

Variable	Calculated t	Significant t	
		0.05	0.01
Total aboveground biomass	0.15	2.07	2.81
Total grasses	1.98	2.07	2.81
Total forbs	2.96	2.07	2.81
Bothriochloa saccharoides	3.55	2.07	2.81
Bouteloua hirsuta	2.68	2.07	2.81
Muhlenbergia reverchonii	0.96	2.07	2.81
Schizachyrium scoparium	2.12	2.07	2.81
Stipa leucotricha	0.38	2.07	2.81
Amphiachyris drancunculoides	0.73	2.07	2.81
Carex microdonta	0.12	2.07	2.81
Phyla nodiflora	7.21	2.07	2.81
Litter	9.49	2.07	2.81

Water and Nitrogen Effects

The water treatment at the Fort Hood site increased annual water supply by only 4%, and this treatment had only minor effects on aboveground biomass (Tables 12 and 31). The water treatment increased the total aboveground biomass

for 8 of the 12 composite variables, compared to control, and decreased above-ground biomass of the remaining 4 variables. However, changes in 4 of these 12 variables (3 increase, 1 decrease) were less than 1 g/m^2. EDYS simulated the response patterns of 6 of these 12 variables correctly.

EDYS simulation accuracies were similar between the added water and precipitation-only treatments (Table 31). EDYS simulations were slightly more accurate for the added water treatment for total aboveground biomass, *Carex micro-donta*, and *Amphiachyris drancunculoides*, and slightly more accurate for the precipitation-only treatment for litter, total grasses, total forbs, *Bothriochloa saccharoides*, *Muhlenbergia reverchonii*, *Schizachyrium scoparium*, and *Stipa leucotricha*.

Relative to the nitrogen availability treatments, EDYS simulations of total aboveground biomass were most accurate (99%) for the control plots (moderate N, Table 33). Simulation accuracy for the high-nitrogen treatment was 88% and the accuracy for the low-nitrogen treatment was 83%. For total grasses, the simulations were most accurate (99.7%) for the high-nitrogen treatment, followed by the control (92%) and low-nitrogen (75%). The reverse pattern resulted for total forbs; the low-nitrogen treatment simulations were most accurate (83%), followed by control (66%) and high-nitrogen (49%).

Based on the total weighted score, the overall EDYS simulations for species were most accurate for the low-nitrogen plots (90%). In general, the simulations were equally accurate among the nitrogen treatments for individual species of grasses. The weighted score sums for grasses were 0.566 for high-nitrogen, 0.524 for moderate-nitrogen, and 0.559 for low-nitrogen (Table 33). However, the simulation accuracies for the forb species decreased as nitrogen level increased.

These results indicate that the EDYS model is more accurate in simulating response to nitrogen by grasses than it is by forbs. This is not surprising since (1) there are more data available on nitrogen-response by these species of grasses than these species of forbs, and (2) the forb composite variables used in this EDYS application, especially the variable used for most perennial forbs (*Phyla nodiflora*), included a large number of diverse species.

Table 32. EDYS validation results for the water treatment in the little bluestem grassland at Fort Hood.

Variable	Sampled	Predicted	Ratio	Relative Biomass	Weighted Score
Added water					
Total aboveground	209.4	208.7	0.997		
Litter	46.3	155.8	0.297		
Total grasses	154.2	178.1	0.866	0.737	0.638
Total forbs	55.1	30.6	0.555	0.263	0.146
Total by lifeform					0.784
Bothriochloa saccharoides	38.4	20.3	0.529	0.183	0.097
Bouteloua hirsuta	8.6	28.6	0.301	0.041	0.012
Muhlenbergia reverchonii	6.3	2.9	0.460	0.030	0.014
Schizachyrium scoparium	95.8	119.3	0.803	0.457	0.367
Stipa leucotricha	5.1	7.1	0.718	0.024	0.017
Amphiachyris drancunculoides	35.8	25.2	0.704	0.171	0.120
Carex microdonta	2.5	2.5	1.000	0.012	0.012
Phyla nodiflora	16.8	2.9	0.173	0.080	0.013
Total for species					0.652
Precipitation only					
Total aboveground	205.9	210.2	0.980		
Litter	53.1	159.4	0.333		
Total grasses	162.2	177.9	0.906	0.788	0.714
Total forbs	43.6	32.3	0.741	0.212	0.157
Total by lifeform					0.871
Bothriochloa saccharoides	37.8	20.6	0.545	0.184	0.100
Bouteloua hirsuta	6.4	21.3	0.300	0.031	0.009
Muhlenbergia reverchonii	4.6	3.7	0.804	0.022	0.018
Schizachyrium scoparium	107.5	127.2	0.845	0.522	0.441
Stipa leucotricha	5.9	5.1	0.864	0.024	0.021
Amphiachyris drancunculoides	25.3	27.3	0.927	0.123	0.114
Carex microdonta	2.4	2.3	0.958	0.012	0.011
Phyla nodiflora	15.9	2.8	0.176	0.077	0.014
Total for species					0.728

Note: Sampled and predicted values are biomass values (g/m^2) for October 1999. Weighted score = Ratio x Relative biomass.

Table 33. EDYS validation results for the nitrogen availability treatment in the little bluestem grassland at Fort Hood.

Variable	Sampled	Predicted	Ratio	Relative Biomass	Weighted Score
High N					
Total aboveground	238.3	208.4	0.875		
Litter	45.4	138.6	0.328		
Total grasses	178.8	179.3	0.997	0.750	0.748
Total forbs	59.5	29.1	0.489	0.250	0.122
Bothriochloa saccharoides	44.9	25.0	0.557	0.188	0.105
Bouteloua hirsuta	7.3	11.2	0.652	0.031	0.020
Muhlenbergia reverchonii	6.3	3.0	0.476	0.026	0.012
Schizachyrium scoparium	116.8	137.3	0.851	0.490	0.417
Stipa leucotricha	3.5	2.9	0.829	0.015	0.012
Amphiachyris drancunculoides	33.3	24.9	0.747	0.140	0.105
Carex microdonta	4.9	1.9	0.388	0.021	0.008
Phyla nodiflora	21.4	2.3	0.107	0.090	0.010
Total for species					0.689
Moderate N					
Total aboveground	209.7	208.1	0.992		
Litter	55.8	164.6	0.339		
Total grasses	162.0	177.0	0.915	0.773	0.707
Total forbs	47.5	31.1	0.655	0.227	0.149
Bothriochloa saccharoides	41.3	17.1	0.414	0.186	0.077
Bouteloua hirsuta	4.1	24.7	0.166	0.018	0.003
Muhlenbergia reverchonii	7.4	3.8	0.514	0.035	0.018
Schizachyrium scoparium	100.7	123.8	0.813	0.480	0.390
Stipa leucotricha	8.6	7.6	0.884	0.041	0.036
Amphiachyris drancunculoides	29.1	25.2	0.866	0.139	0.120
Carex microdonta	1.4	2.8	0.500	0.007	0.004
Phyla nodiflora	17.0	3.1	0.182	0.081	0.015
Total for species					0.663
Low N					
Total aboveground	175.0	211.9	0.826		
Litter	47.9	169.6	0.282		
Total grasses	133.9	177.8	0.753	0.765	0.576
Total forbs	41.1	34.1	0.830	0.235	0.195
Bothriochloa saccharoides	28.0	19.3	0.689	0.160	0.110
Bouteloua hirsuta	11.2	39.0	0.287	0.064	0.018
Muhlenbergia reverchonii	2.8	3.1	0.903	0.016	0.014
Schizachyrium scoparium	87.3	108.7	0.803	0.499	0.401
Stipa leucotricha	4.6	7.7	0.597	0.026	0.016
Amphiachyris drancunculoides	29.4	28.7	0.976	0.168	0.164
Carex microdonta	1.1	2.5	0.440	0.006	0.003
Phyla nodiflora	10.6	3.0	0.283	0.606	0.171
Total for species					0.897

Note: Sampled and predicted values are biomass values (g/m^2) for October 1999. Weighted score = Ratio x Relative biomass.

Vegetation Responses to Cattle Grazing, Drought, and Juniper Invasion

The EDYS model parameterized for the experimental plots in the little bluestem prairie at Fort Hood was used to simulate 40-year plant community responses to stresses from cattle grazing, drought, and invasion by Ashe juniper. Results of these simulations are described in the following sections.

Effects of Cattle Grazing

Forty-year simulations were run under three stocking rates to evaluate the effects of cattle grazing on production and composition of the little bluestem grassland (Table 34). Cattle grazing, at the stocking rates evaluated in these simulations, had much less of an impact on this grassland than it did on the black grama desert grassland (Table 24). With no grazing, dominance by little bluestem increased over the 40 years and the abundance of silver bluestem and hairy grama also increased. Texas wintergrass decreased, probably because of the increased competition from the bluestem midgrasses. Aboveground biomass remained relatively constant, except for a drought-induced decrease in Year 20.

Light grazing by cattle (40 Ac/AU, year long) resulted in a slower increase in little bluestem dominance and a significant increase in hairy grama, compared to no grazing. Silver bluestem remained constant and Texas wintergrass decreased. Total aboveground biomass decreased by about 8% over the 40-year period. This decrease was the result of the decrease in Texas wintergrass. Moderate grazing by cattle (20 Ac/AU, year long) had a much greater impact on Texas wintergrass than did light grazing, decreasing the production of this species to half its ungrazed value after 40 years. The site dominant, little bluestem, increased proportionately to the decrease in Texas wintergrass.

Table 34. EDYS simulation of effects of cattle stocking rate on end-of-growing season (October) aboveground biomass (g/m^2) and relative biomass (%) of a little bluestem grassland at Fort Hood over a 40-year period with average precipitation.

	No Grazing				40 Ac/AU				20 Ac/AU			
	10	20	30	40	10	20	30	40	10	20	30	40
Aboveground biomass												
Silver bluestem	34	21	38	46	26	11	22	27	51	20	36	45
Hairy grama	23	21	33	48	57	27	50	77	43	20	31	57
Seep muhly	2	1	t	t	2	t	1	t	1	t	t	t
Little bluestem	186	106	178	211	176	81	148	173	258	111	207	230
Texas wintergrass	138	43	76	52	102	50	82	56	50	27	47	27
Forbs	t	t	t	t	t	t	t	t	1	t	t	t
Total	383	192	326	358	364	171	303	333	404	179	321	360
Relative biomass												
Silver bluestem	9	11	12	13	7	6	7	8	13	11	11	13
Hairy grama	6	11	10	13	16	16	17	23	11	11	10	16
Seep muhly	t	t	t	t	t	t	t	t	t	t	t	t
Little bluestem	49	55	55	59	48	47	49	52	64	62	64	64
Texas wintergrass	36	22	23	15	28	29	27	17	12	15	15	8
Forbs	t	t	t	t	t	t	t	t	t	t	t	t

Effect of Precipitation

The effects of changes in precipitation regime were investigated by decreasing each precipitation event over a 40-year period by 10% and then by increasing each precipitation event by 10%. In both cases, the historical seasonal and annual precipitation patterns were retained. Only each daily amount received was decreased or increased.

Decreased precipitation, without cattle grazing, had a significant effect on both aboveground production and species composition (Table 35). Compared to the normal precipitation pattern (Table 34), a 10% decrease in precipitation decreased aboveground production 20 to 30%. Silver bluestem and little bluestem, the taller grasses at this site, became less important in the plant community and hairy grama and Texas wintergrass, the shorter grass species, became more important. This pattern of a shift from taller to shorter grasses as precipitation decreases is expected (Smeins 1994).

Table 35. EDYS simulation of effects of a decreased precipitation regime (10% below normal), with and without cattle grazing, on end-of-growing season (October) aboveground biomass (g/m^2) and relative biomass (%) of a little bluestem grassland at Fort Hood over a 40-year period.

	No Grazing				Light Grazing			
	10	20	30	40	10	20	30	40
Aboveground biomass								
Silver bluestem	12	5	12	16	32	12	22	27
Hairy grama	40	32	37	51	49	29	47	62
Seep muhly	2	1	0	1	1	t	t	t
Little bluestem	90	38	81	100	183	77	141	154
Texas wintergrass	161	61	118	91	78	30	61	45
Forbs	t	t	t	t	t	t	t	t
Total	306	137	250	260	343	148	272	289
Relative biomass								
Silver bluestem	4	4	5	6	9	8	9	10
Hairy grama	13	23	15	19	14	20	17	21
Seep muhly	1	1	0	t	t	t	t	t
Little bluestem	29	28	32	38	53	52	52	53
Texas wintergrass	53	45	47	35	23	20	22	16
Forbs	t	t	t	t	t	t	t	t

Decreased precipitation with cattle grazing produced a different response in the vegetation than decreased precipitation without grazing (Table 35). Under light grazing (40 Ac/AU), aboveground production also decreased, relative to normal precipitation, but by 10 to 15%, or about half the decrease without grazing. In addition, species composition remained similar to the pattern under normal precipitation with light grazing (Table 34). The relative biomass values of the bluestems were higher than with no grazing and the shorter grasses were lower. The reason for the different compositional pattern between grazing and no grazing under decreased precipitation was the fact that the shorter grasses are more preferred forage species under some conditions, especially during dormant periods, than the coarser midgrasses. Therefore, hairy grama and Texas wintergrass received heavier grazing pressure than the bluestems.

Under higher precipitation and no cattle grazing, aboveground production increased 10 to 20% (Table 36) over the normal precipitation pattern. Species composition was also affected, with the relative importance of the midgrasses (silver bluestem and little bluestem) increasing and the relative importance of the shorter grasses (hairy grama and Texas wintergrass) decreasing. This pattern is logical. In the central prairies of the United States, the composition of mid- and tallgrasses increases and the composition of shorter grasses decreases (Weaver 1954).

Table 36. EDYS simulation of effects of an increased precipitation regime (10% above normal), with and without cattle grazing, on end-of-growing season (October) aboveground biomass (g/m^2) and relative biomass (%) of a little bluestem grassland at Fort Hood over a 40-year period.

	No Grazing				Light Grazing			
	10	20	30	40	10	20	30	40
Aboveground biomass								
Silver bluestem	53	31	52	58	38	20	35	40
Hairy grama	27	16	23	45	52	19	33	64
Seep muhly	2	1	1	t	1	t	t	t
Little bluestem	257	134	223	246	274	134	233	253
Texas wintergrass	129	43	83	55	90	37	67	42
Forbs	t	t	t	t	t	t	t	t
Total	468	225	381	404	456	211	368	399
Relative biomass								
Silver bluestem	11	14	14	14	8	9	10	10
Hairy grama	6	7	6	11	11	9	9	16
Seep muhly	t	t	t	t	t	t	t	t
Little bluestem	55	59	58	61	60	64	63	63
Texas wintergrass	28	19	22	13	20	18	18	11
Forbs	t	t	t	t	t	t	t	t

Light grazing by cattle had only a slight effect on aboveground biomass, reducing it by 5% or less (Table 36). Cattle grazing had a slightly greater effect on species composition. Compared to no grazing, relative biomass of little bluestem and hairy grama increased and silver bluestem and Texas wintergrass decreased. The decrease in Texas wintergrass was probably the result of both heavy utilization by cattle and increased competition from little bluestem. This increased competition resulted from more favorable ecological conditions for little bluestem under the higher precipitation regime. Increased competitive advantage of little bluestem under the higher precipitation regime may also explain the decrease in relative biomass of silver bluestem. Within its range, silver bluestem occurs more abundantly on drier sites than does little bluestem (Gould 1975:593, McLendon 1991).

Effects of Juniper Invasion

Invasion of Ashe juniper (*Juniperus agnei*) was modeled by adding 1 g/m^2 of juniper seed to the initial seed bank of each of the 24 plots. Forty-year simulations were then conducted for each plot under a normal precipitation regime and light grazing (40 Ac/AU) by cattle. Other than adding the juniper seed, no changes were made to the initial conditions of each plot.

Without fire, the EDYS simulations indicate that juniper will become the dominant species on the site within 20 years (Table 37). By Year 20, juniper will contribute 46% of the aboveground biomass of the plant community, followed by little bluestem (26%) and Texas wintergrass (16%). Over the next 20 years, aboveground biomass of juniper almost doubles, but its relative biomass remains about the same. Composition of little bluestem and Texas wintergrass continue to decrease. Composition of hairy grama increases slightly and silver bluestem relative biomass remains relatively constant. The invasion of juniper decreases the aboveground biomass of the grasses by 14% over the 40-year period, from 358 g/m^2 in Year 10 without juniper (Table 33) to 307 g/m^2 in Year 40 with juniper (Table 36).

Aboveground biomass of juniper increased by 30% between Year 20 and Year 30, and by 34% between Year 30 and Year 40 (Table 37). Without fire, this rate of increase would probably continue. At that rate, juniper would comprise 80 to 90% of the biomass of the site by Year 60.

Ten-year controlled burns (simulated in February of Years 10, 20, and 30) had little effect on juniper biomass or composition in the first 20 years, but had significant effect in the second 20 years (Table 37). In Year 40, the 10-year burn scenario decreased juniper aboveground biomass by 50% and reduced its relative biomass by 42%, compared to the unburned scenario. This burn scenario increased the production and composition of silver bluestem and little bluestem and deceased the production and composition of hairy grama and Texas wintergrass.

Table 37. EDYS simulation of the effect of fire on the invasion of a little bluestem grassland by Ashe juniper, Fort Hood, under a normal precipitation pattern and with light grazing by cattle.

	No Fire				10-Year Burn				20-Year Burn			
	10	20	30	40	10	20	30	40	10	20	30	40
Aboveground biomass (g/m²)												
Ashe juniper	73	135	175	234	71	117	129	115	73	119	153	173
Silver bluestem	26	11	18	21	47	19	30	39	26	17	22	24
Hairy grama	39	26	48	67	30	20	24	31	39	30	27	57
Seep muhly	1	1	t	t	4	1	1	1	1	2	t	t
Little bluestem	174	76	137	150	288	124	196	244	174	115	138	161
Texas wintergrass	117	47	89	69	49	15	41	39	117	13	100	73
Forbs	1	t	t	t	3	1	t	t	1	t	t	1
Total	431	296	467	541	492	297	421	469	431	296	440	489
Relative biomass (%)												
Ashe juniper	17	46	37	43	14	39	31	25	17	40	35	35
Silver bluestem	6	4	4	4	10	6	7	8	6	6	5	5
Hairy grama	9	9	10	12	6	7	6	7	9	10	6	12
Seep muhly	t	t	t	t	1	t	t	t	t	t	t	t
Little bluestem	40	26	29	28	59	42	47	52	40	39	31	33
Texas wintergrass	27	16	19	13	10	5	10	8	27	4	23	15
Forbs	t	t	t	t	1	t	t	t	t	t	t	t

This fire-induced pattern of an increase in midgrasses and a decrease in shorter grasses is primarily the result of spatial characteristics of these grass types. The midgrasses occur primarily as patches of prairie between clumps of juniper and the shorter grasses occur primarily in openings in the canopies of the taller species, either within the bluestem prairie or in the ecotones between the prairie and the juniper (Figure 10). As the juniper canopies expand, the primary effect is to decrease the composition of the midgrasses, since the ecotones also expand. As the juniper canopies close over time, the shorter grasses also decrease as the ecotones decrease and then vanish. As the juniper canopies contract, in response to fire for example, the juniper-prairie ecotones also contract, decreasing the composition of the shorter grasses, and the prairie expands, increasing the composition of the midgrasses.
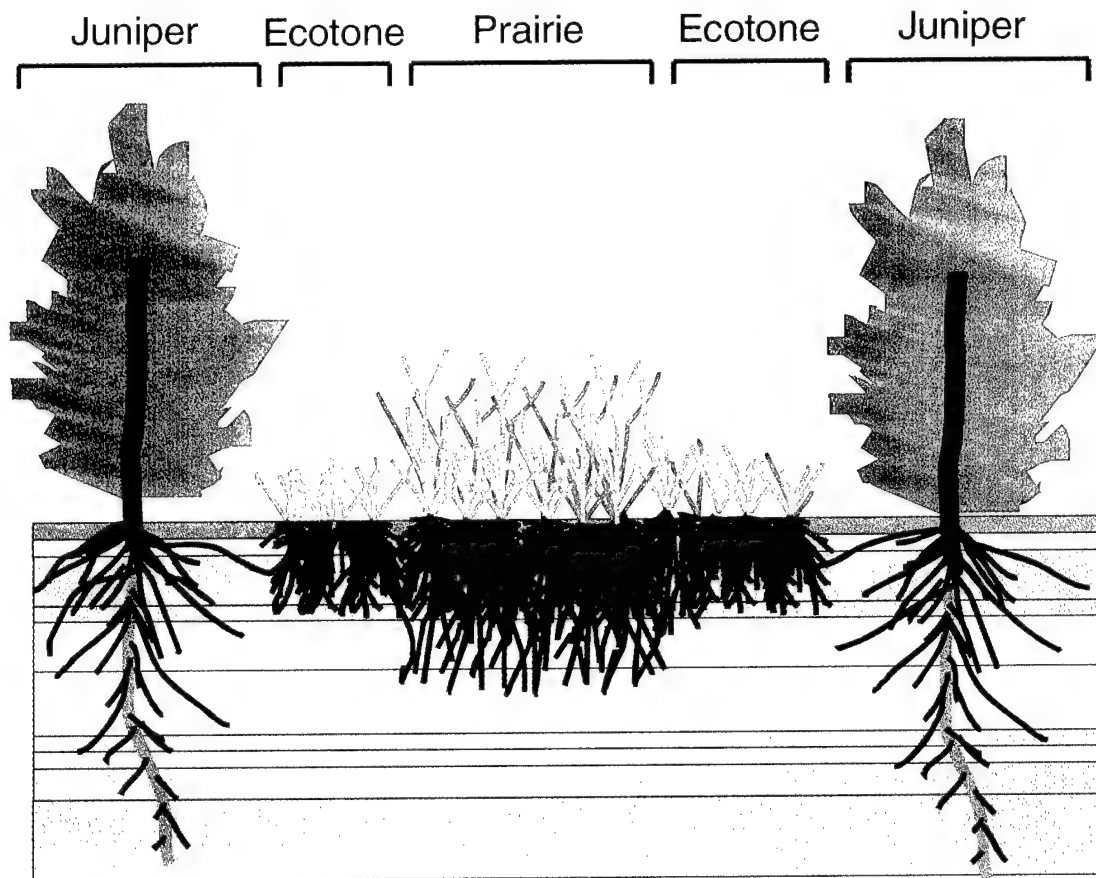
Figure 10. Spatial pattern associated with juniper invasion of bluestem prairie, Fort Hood.

The burns also increased the production of seep muhly and forbs. Overall, the grasses were as productive with juniper present and the 10-year burn scenario (Table 37) as they were with juniper not present (Table 34).

Burning at 20-year intervals produced results intermediate between the unburned and burned at 10-year interval scenarios, but more similar to the unburned scenario than to the 10-year burn scenario (Table 37). This indicates that a 20-year burn interval is too infrequent for effective control of juniper in this ecosystem.

Estimated Water Use

A major use of EDYS at Fort Hood and at other application sites, is to simulate the effect of vegetation changes on water use, with subsequent impacts on surface and subsurface movement and discharges from seeps, springs, and streams. To date, EDYS simulations of subsurface water movement have not been validated on a gauged watershed. However, water use by plants is a major component of EDYS and is a primary control mechanism for plant productivity. This mechanism, combined with the validated accuracy of EDYS in predicting plant

productivity, suggests that EDYS may be a useful tool in predicting water dynamics within the rooting depths of plants.

EDYS was used to simulate the annual water balance at the study site at Fort Hood under three scenarios: (1) a little bluestem grassland community without juniper, (2) the same little bluestem grassland, but with Ashe juniper allowed to invade without fire, and (3) the juniper-invaded bluestem grassland with controlled burns in February of every tenth year (Table 38). In all three scenarios, the normal precipitation and light grazing by cattle (40 Ac/AU) were used.

The values in Table 38 are 40-year sums (i.e., the total amount of water within each respective category over the entire 40-year simulation period). Subsurface export refers to the amount of water that moves past the rooting zone of the plant community. As such, it represents the maximum amount of water that could (1) remain in the soil profile, (2) move vertically below the rooting zone, and (3) move laterally offsite.

Total precipitation received at the site, based on the 40-year historical precipitation data used in the simulation, was 32,121 mm (Table 38). Evapotranspiration from the grassland community with no juniper, was 31,537 mm, or 98% of the precipitation received. The 40-year simulated surface runoff was 48 mm and the subsurface export was 778 mm. Untreated juniper invasion increased surface runoff slightly and decreased subsurface export by 23%.

Controlled burning at 10-year intervals resulted in less subsurface export than the unburned juniper-grassland because of increased transpiration by the burned plant community. It would normally be assumed that the use of controlled burns as a management tool to reduce juniper in these grasslands would also reduce the amount of water used, and therefore increase the amount of water exported. However, in this case the increased productivity of grasses in the burned community more than compensated for the decrease in juniper (Table 37). Land managers could use the EDYS model to gain a better grasp of factors involved in meeting intended management goals.

The subsurface export values on both the grassland and juniper-grassland communities may seem surprising low. Total simulated export, surface and subsurface, from the grassland community was only 826 mm over 40 years (Table 38), or an average of 20.7 mm (0.8 acre-inch) per year. However, it should be noted that this was an average from the 24 vegetated plots only. Other parts of the watershed would have much higher export rates. Rock outcrops, for example, would have almost 100% export (surface + subsurface). If a watershed was composed of 40% bluestem prairie, 40% juniper-grassland, and 20% rock outcrops

and bare ground, average export would be on the order of 175 mm (6.9 acre-inches) per year (i.e., the weighted average of the three types). This would equal about 22% of annual precipitation.

Table 38. EDYS simulations of 40-year water balance on a little bluestem grassland at Fort Hood with and without juniper invasion and with and without fire.

	Grassland, No Juniper	Juniper-Grassland No Fire	Juniper-Grassland 10-year Burns
kg/m^2 = mm			
Precipitation	32,121	32,121	32,121
Canopy evaporation	3,244	2,930	2,293
Soil evaporation	1,542	1,475	2,139
Transpiration	26,751	27,388	27,502
Evapotranspiration	31,537	31,793	31,934
Surface runoff	48	52	48
Subsurface export	778	599	467
Acre-inches			
Precipitation	1,265	1,265	1,265
Canopy evaporation	128	115	90
Soil evaporation	61	58	84
Transpiration	1,053	1,078	1,083
Evapotranspiration	1,242	1,251	1,257
Surface runoff	2	2	2
Subsurface export	31	24	18
1000 Gals/AC			
Precipitation	34,357	34,357	34,357
Canopy evaporation	3,468	3,133	2,451
Soil evaporation	1,648	1,577	2,287
Transpiration	28,597	29,278	29,400
Evapotranspiration	33,713	33,988	34,138
Surface runoff	51	56	51
Subsurface export	832	640	499

Note: The sum of the evapotranspiration, runoff, and subsurface export values do not equal the precipitation values because of differences in starting and ending soil moisture levels.

6 Conclusions and Recommendations

Conclusions

The EDYS model has been demonstrated to be an effective tool to simulate vege-
tation responses to natural stressors and management scenarios in both the de-
sert grassland at Fort Bliss and the bluestem prairie at Fort Hood. Second-year
validation results indicate that the EDYS simulations were 95 to 99% accurate
for total aboveground biomass, 82 to 93% accurate for the dominant species, and
70 to 83% accurate for individual species on a weighted average basis. EDYS
effectively demonstrates the complex factors in vegetational responses to water,
nitrogen, fire, and cattle grazing.

Forty-year simulations for the Fort Bliss black grama community indicate that :
- shrubs will increase in the absence of fire,
- a fire frequency of less than 15 years is probably detrimental to the black
  grama community,
- a cattle stocking rate of 60 Ac/AU is too heavy for the black grama grassland,
- long-term (> 20 years) decreases in precipitation will decrease the abundance
  of black grama, and
- drought approximately doubles the detrimental effect of overgrazing by cat-
  tle.

Forty-year simulations for the Fort Hood little bluestem community indicate
that :
- a cattle stocking rate of 40 Ac/AU will not have detrimental effects on this
  community and a stocking rate of 20 Ac/AU will reduce some species but not
  the overall productivity of the community,
- a long-term 10% decrease in precipitation would result in significant changes
  in the plant community, increasing the relative amounts of shorter grasses
  and decreasing the amount of the midgrasses,
- without fire, juniper will dominate the site in 20 years,
- 10-year fire frequencies were effective in reducing the amount of juniper and
  allowing the community to remain dominated by little bluestem and 20-year
  fire frequencies were much less effective in maintaining the grassland, and
- juniper invasion reduced water export from the grassland community by
  23%.

These results indicate that the EDYS model is more accurate in simulating response to nitrogen by grasses than it is by forbs. This is not surprising since (1) there are more data available on nitrogen-response by these species of grasses than these species of forbs, and (2) the forb composite variables used in this EDYS application, especially the variable used for most perennial forbs (*Phyla nodiflora*), included a large number of diverse species.

Recommendations

It is recommended that two primary revisions be made to these EDYS applications to incorporate the results of the validations. First, additional plant species should be added. A significant improvement in accuracy could be achieved by adding *Bothriochloa ischaemum*, *Bouteloua curtipendula*, and *Sporobolus asper*, and at least one other perennial forb to the Fort Hood model. Second, improvements should be made to the decomposition-mineralization and nitrogen cycling components, and the groundwater component should be validated.

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14. ABSTRACT

Precipitation patterns, including the effects of long-term droughts or above average precipitation and the interactions with nitrogen availability, often have enough influence on plant growth that the effects of our use or management of land are not apparent. This is especially true because of the need to judge changes in land condition over periods of months to years.

One of the primary information requirements identified by Army land managers and trainers is the need to be able to project the impacts of training and management strategies on the amount of plant cover protecting the soil. Managers also need to know how long it takes a plant community to recover to the desired plant cover level after use.

The purpose of this research project was to test the ability of the Ecological DYnamics Simulation (EDYS) model to accurately project plant dynamics given a wide range of precipitation patterns and nitrogen availability over a period of years to decades.

The results of this research show that EDYS did accurately simulate changes in plant cover over the 2-year research period and the patterns EDYS projects over 40-year simulations closely match the patterns seen on the ground in 40-year old research plots.

15. SUBJECT TERMS

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